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# PRODUCTION OF PLANKTON IN THE OSLO FJORD

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# Investigations of the Production of Plankton in the Oslo Fjord

by

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Since BRANDT published his first treatise "Ueber den Stoffwechsel des Meeres" (1899), it has been regarded as extremely probable that the production of organic matter, both in the sea and in fresh water, is largely regulated by the occurrence of soluble substances which are nutritive to plants, the principal of which is probably nitrogen. BRANDT proved that there are carried out to sea by rivers considerable quantities of nitrogenous compounds in solution, and these are partly consumed by the pelagic algæ, and are also partly attacked by denitrifying bacteria, which in certain conditions can transform nitrates into free nitrogen. As the bacteria work more energetically at higher temperatures, BRANDT saw in this competition of bacteria with algæ a reason why the tropical and sub-tropical marine areas are comparatively poor in this respect and that the production in temperate seas appears to be greater in spring and autumn than in summer. NATHANSOHN (1906, 1908, 1909), on the other hand, emphasised that the uppermost layers of water, where the light is sufficient to enable the plants to live, must constantly be deprived of considerable quantities of substances nutritive to plants, when plants and animals and their dead remains sink towards the bottom and create conditions of nutrition for animal life in the depths of the sea. There must therefore be conditions for the development of a relatively abundant vegetable life where the masses of water from the depths rise towards the surface, either by vertical circulation, e. g. as seen in fresh water, where the conditions of temperature produce convection currents in spring and autumn, or by the movement of large masses of water.

In order to enter more deeply into these questions it was necessary to obtain material in order to estimate the true value of the plankton production under various conditions. It should be possible to find a starting point for such investigations in tracing the annual development of the coastal plankton on the coasts

of Northern Europe. It appears to be a general phenomenon that, after a relatively poor period in December—January, there begins a very rich growth of diatoms, somewhat earlier or later at various places, generally in March on the south coast of Norway. This growth is in most years of short duration. As soon as the surface water begins to grow warm, the diatoms disappear, and the vegetation of ceratia, which by degrees replaces them, increases comparatively slowly, so that it is not until September—October that we find a new maximum.

Already in 1907—1908 GRAN and NATHANSOHN endeavoured to trace this development by quantitative determinations of the occurrence of algæ in the Oslo Fjord at the Biological Station at Drøbak, whilst at the same time determinations were made of quantities of soluble nitrogen compounds occurring in sea water (NATHANSOHN 1908). The investigations met with a great difficulty, viz. that the quantity of plankton in the Oslo Fjord varies greatly from day to day on account of the movement of the mass of water in and out of the fjord, and these changes are much greater than the variations which might be attributed to changes in the conditions of life. It was therefore necessary to find another method of determining the daily growth of the various species. We therefore endeavoured, on the one hand, to carry out culture experiments under conditions which as far as possible resembled those out in the fjord; on the other hand we aimed at determining the daily percentage growth of the ceratia according to the method which at the same time was employed by APSTEIN (1910). A preliminary survey of the results is given in GRAN's contribution "Pelagic Plant Life" in MURRAY and HJORT's handbook "Depths of the Ocean" (1912) p.p. 307—386. We consider that it is superfluous to publish a detailed account now that, with improved methods, we have been able to carry out the investigations which will be described in the following pages.

The method employed in 1907—1908 for the quantitative determination of plankton was based on the investigation of living material, whereby the possibility of investigating large continuous series of material collected simultaneously was greatly restricted. Considerable progress was therefore made when it became possible to preserve samples of water for the quantitative determination of plankton in accordance with the method described by GRAN (1912). This has the great advantage that infusoria and flagellata are also preserved with their cilia fully extended. These investigations otherwise correspond to the centrifugation method described by LOHMANN (1902, 1908) which has been found to give results of fully sufficient accuracy. The problem which we placed before us and for the solution of which the investigations described below should give some contribution were:— In the first place, to study the factors which determine the conditions of production as they evince themselves in the fjord water, partly by means of direct investigations in the open fjord water, and partly by culture experiments with the plankton organisms of the fjord water under conditions which approximate as far as possible to the natural ones. In the second place, we endeavoured to find a workable

and relatively easily determined figure for the actual size of the production independently of the time wasting methods, through which by counting the plankton organisms there is obtained a quantitative figure for the production.

It has been found from earlier investigations (GAARDER 1915) that there is often a very distinctly demonstrable agreement between the occurrence and extent of the phytoplankton and the changes in the quantity of oxygen in the uppermost layers of water in the fjord. Both the quantity of oxygen and the content of carbonic acid of sea water and thereby also its reaction or hydrogen ion concentration are influenced directly by the metabolic processes of the plankton (GAARDER 1917), and must therefore be assumed through their changes to make it possible to estimate the production, independently of the determination of plankton.

The photosynthesis of the algæ, on the one hand, and the respiration of the algæ, bacteria and animals on the other hand doubtless act in contrary directions; but in March, when the temperatures are very low, and the algæ, especially diatoms, entirely predominate over the other constituents of the plankton, the photosynthesis is quite predominant and the determinations of oxygen in particular (or the determinations of the total amount of carbonic acid) must therefore be expected to give quite good minimum values for the photo-synthesis of the plankton algæ and thereby for the production of organic substance. A determination of the oxygen dissolved in sea water is easily performed by the aid of WINKLER's method (vide e. g. GAARDER 1915). A determination of oxygen presents many advantages over a determination of the total amount of carbonic acid in sea water, both as regards the collection, preservation and analysis of the samples of water. We therefore determined to investigate the connection between the production of plankton and the variations of the content of oxygen in sea water.

As furthermore the reaction of a medium (its hydrogen ion concentration) exercises the greatest influence upon the course of the vital processes in an organism and has also been found to be of decisive importance for the development of the organisms (with regard to literature vide e. g. R. HÖBER: Physikalische Chemie der Zelle und der Gewebe, 5 Auflage, Leipzig 1924 and CLARK, W. M.: The Determination of hydrogen ions, 2nd Edition, Baltimore 1922), we therefore considered that it would be of advantage also to investigate how the reaction of sea water varied with the plankton production.

The investigations were carried out in collaboration at the Biological Station at Drøbak by the present authors, GAARDER being responsible for the chemical part of the investigations and GRAN for the biological part. As regards the method of collection and investigation, the following can be stated: Surface water was collected by the aid of a wooden bucket, while water from deeper layers was collected by the aid of NANSEN's reversing tap water bottle. Samples were taken of the water for analysis and culture experiments. The plankton content of the water

was determined by GRAN's method (l. c.). The temperature of the sea water at the surface was determined by the aid of an ordinary thermometer, graduated to show 1/10th°, the temperature in deep water by the aid of a RICHTER's reversing thermometer. The content of salt was determined by titration of chlorine after MOHR, and by the aid of the values found for temperature and the content of salt, the density of the sea water ($\sigma_t$) was determined according to M. KNUDSEN's hydrographic tables. The oxygen in solution was determined according to WINKLER's method. The reaction (concentration of hydrogen ions given by the corresponding $P_H$-value) was determined according to SØRENSEN and PALITZSCH's colorimetric method (SØRENSEN, S. P. L. und PALITZSCH, S.: Über die Messung der Wasserstoffionenkonzentration des Meerwassers. Biochem. Ztschr. **24**, 387 and Compt. rend. de Carlsberg **9**, 8). The oxidizability of the sea-water i. e. the amount of oxygen absorbed from permanganate under quite definite conditions of research was determined according to RUPPIN's method (RUPPIN, E.: Über die Oxydierbarkeit des Meerwassers durch Kaliumpermanganat, Publ. de Circonstance, No. 20 (Conseil Permanent international pour l'exploration de la Mer, Copenhagen 1904). When the sea water was found to contain sulphuretted hydrogen, the latter was determined according to a method earlier described by GAARDER (1915, p. 35).

We found it advisable to carry out the investigations at two different times of the year, on the one hand in March, when the phyto-plankton of the fjord is in vigorous development, so that it must be assumed that the algæ have the most favourable conditions of life, and on the other hand in the late summer whilst the characteristic contrast still exists between a warm and specifically light surface layer and colder masses of water in the depths. In the middle of the summer, on account of the high temperature, the conditions are less favourable for culture experiments.

The investigations were, therefore, carried on in March 1916 and in August—September 1917.

## 1. The Oslo Fjord Plankton, March 1916.

Earlier investigations which have only partly been published (HJORT and GRAN 1900) showed that the plankton of the Oslo Fjord is quantitatively poor during the months December—February. On the other hand, we find in March an extremely rich plankton, especially of diatoms, in some years somewhat earlier, in others later. In 1916 it was still poor on the 8th March, as shown by Table I; the predominant species were *Lauderia glacialis* and *Thalassiosira gravida*; they were most frequent at the surface, and even at a depth of 10 metres there were one third as many as at the surface. At 20 metres, where the salinity and temperature exhibit conditions of transition between the surface layers (with salinity 30—31 ‰ and temperature 0—2°) and the deeper layers with salinity over 33 ‰

and temperature over 4°, there was still a number of diatoms to be found, especially *Thalassiosira gravida*. They occur very scantily in deep water, so that the scattered observations of individual cells or individual chains of cells have a chance character. The water there is also distinctly undersaturated with oxygen (saturation percent 92).

On March 15 (Table 2) the surface layer had become somewhat richer; but at the same time the layer containing plankton had become thinner, since in the course of a week there had prevailed practically speaking a constant north wind, so that the surface layers had in general moved outwards, whilst the deep layers had approached the surface. Even at a depth of 2 metres the salinity was 34.15 ‰ and the temperature 5.57°. The sample from 5 metres indicates the stage of transition between the upper layers containing plankton and the meagre deep layers, and already at 10 metres we find the deep layers in their typical condition. The species were the same as those found one week previously, *Lauderia glacialis* and *Thalassiosira gravida*; the determination of oxygen showed non-saturation even at the surface and relatively marked non-saturation from 2 metres downwards (84.5 %—81 %).

On March 22 (Table 3) we still found the same species and on the whole in the same relative quantities. But the total amount had increased 6—8 times, and some species, which had previously only occurred in such small quantities that they could not be shown to be present in the samples of 100 cc. examined, were now evident even in samples of water of only 25 cc. The green flagellata *Eutreptia Lanowii*, previously only found by Triest by Steuer, had multiplied quite extensively. The surface layers (0—2 m.) were still those containing the largest quantities. The salinity was there 30—31 ‰, and the temperature 1.0°. The deeper water layers (20—30 m.) with a temperature of 6.1° and salinity 34,70 ‰ were still particular poor; the transition layers (5—10 m.) exhibited in every respect a condition of transition. *Biddulphia sinensis* appeared in 20 metres and had evidently been driven in with the reaction-current below the surface layers. The oxygen-investigations also gave the same result; the surface layers of water were almost saturated with oxygen, whilst the deep layers were distinctly non-saturated.

On March 23 a great storm came from the south and this immediately altered the situation in the surface layers of the fjord. Already with the naked eye it was possible to see that the water had become much more opaque than on the previous days. Therefore, as soon as the storm ceased on the 24th, we immediately made fresh investigations, the results of which are presented in Table 4.

The total density of diatoms had at once been increased to more than ten times as much, and the plankton bearing surface water had been forced together to a depth of over 20 metres. It was not until a depth of 50 metres was reached that we found layers of water poor in plankton, with a temperature of

6° and salinity 34.7 ‰. At a depth of 30—40 metres were found mixed layers with conditions of transition between the surface layers and the deeper ones.

But the change was found to be not only quantitative. The community of species had altered as regards its composition. With the species which at that time are characteristic of the inner part of the fjord, (*Lauderia glacialis*, *Thalassiosira gravida*, *Eutreptia Lanowii*) we find an entire series of other kinds which have been driven in from the outer part of the fjord, or from the Skagerak, above all species of *Chaetoceras*, and further *Biddulphia aurita*, *Thalassiosira Nordenskiøldii* and *Skeletonema costatum*, *Laboea vestita* and *Mesodinium*. In the case of the majority of species the maximum lies at a depth of 5—10 metres. Investigations of oxygen showed oversaturation down to and including a depth of 10 metres, as a sign of the lively photo-synthesis of the abundant plankton.

One week later, on April 1 (Table 5) the surface layers have still approximately the same thickness, but the layer which then covered the surface had a considerably lower salinity (about 25 ‰), and a lower temperature 0.5°—1°, indicating a greater admixture of fresh water. The quantity of oxygen had increased from 8.3 to 8.8 cc. per litre, i. e. on an average 0.5 cc. per litre, and the oversaturation had increased. The original community of species from the month of March, (*Lauderia glacialis*, *Thalassiosira gravida* and *Eutreptia Lanowii*) had now quite receded in comparison with the species from the Skagerak (*Biddulphia aurita*, *Chaetoceras* species and above all *Skeletonema costatum* and *Thalassiosira Nordenskiøldii*).

We have already in a previous report (Gran and Gaarder, 1918) shown how the horizontal movements of the plankton in the fjord are entirely dominated by the currents and meteorological conditions. It would scarcely be possible to procure a clearer proof of this dependency.

The investigations in 1916 were interrupted at the beginning of April from external causes; consecutive investigations during the spring were carried out in other years. In some years the rich development of diatoms continues through the month of April until part of May. Whilst *Thalassiosira* is usually predominent in March, the *Chaetoceras* species are usually predominent in April, especially *Ch. constrictum*. By degrees these are replaced by *Leptocylindrus danicus*. When the latter disappears in May—June there is a scanty plankton in the Oslo Fjord, of which *Ceratium longipes* is predominent. But there may be variations in this order from year to year, just as the quantitative alterations may also proceed in a different manner.

### Cultural Experiments.

In order to estimate quantitatively the production of plankton, comparative investigations at one place are not sufficient, because the conditions of current always produce greater variations from day to day than the variations due to

the growth and decrease of the plankton algæ. For this purpose it was necessary to try cultural experiments under conditions which were as near as possible to those present in the sea itself. The well known pure cultures, which were carried out by Allen and Nelson (1910), Allen (1914) with plankton diatoms in Erlenmeyer flasks in a laboratory gave very valuable results; but for our purpose this method was not suitable. We, therefore, endeavoured to hang in the sea closed flasks of natural sea water which had previously been investigated for salinity, quantity of oxygen, and content of plankton. We usually employed one litre flasks with ground glass stoppers, all of which were filled from one and the same supply of sea-water. Both salinity, content of oxygen and concentration of hydrogen ions and plankton were investigated beforehand.

Preliminary investigations showed that the diatoms in all the flasks propagated the first day, even though the flasks were hung up in the dark or wrapped in black cloth. This growth is assumed to be dependent upon the products of assimilation which the algæ had gathered during the previous day. For the final experiments, therefore, the flasks were not filled until the afternoon and were then all placed in a dark cupboard in the laboratory for the night, and one of them was again examined for its plankton the following morning; whilst at the same time the others were suspended in the sea. The system of experimenting will be seen in the appended schematic drawing (Fig. 1). All the flasks were hung from a buoy which was anchored at a depth of 50 metres out in the fjord, in a bay where practically speaking the current could be placed out of consideration.

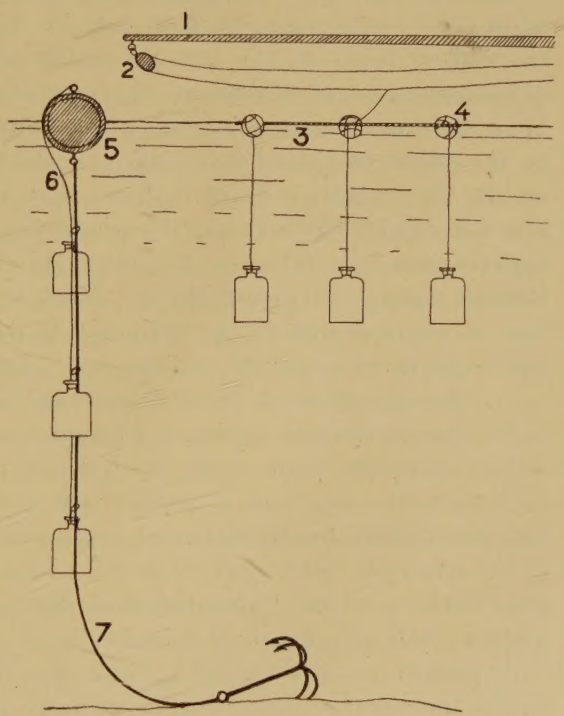


Fig. 1.

Table 6 shows the results of one of these raw culture experiments carried out March 22—25, 1916, with a sample of water obtained from the surface water at Drøbak on the afternoon of the 21st. The flask which was suspended at a depth of 40 metres was wrapped in black cloth in order to give an idea of the development of the algæ in complete darkness.

The table shows that all the diatoms at present prevailing in the fjord bred extensively in the flasks which obtained sufficient light, and the increase in the quantity of oxygen is quite parallel with the increase of the algæ. Also the alterations that were proved to take place in the concentration of hydrogen ions in sea-water — given by means of the corresponding $P_H$-value — distinctly, although faintly showed that the growth causes an increase in the $P_H$-value, i. e. an increasing alkaline reaction, and that the respirative capacities of the plankton and bacteria are able to produce a marked decrease in the $P_H$-value of the sea water in such a comparatively short time as the one in question. In the first place it therefore appears to be an undoubted fact that the vital conditions of the algæ in the flasks in the course of such a short experiment were somewhat normal. No nutritive salts were placed in any of the flasks. The quantities of soluble nutritive matter which the sea water contained at that time of the year were thus adequate for a breeding which corresponds to an increase of at least 60 %—80 % per 24 hours, at a temperature of about 1.4°. It appears from our system of research that the culture flasks at the various depths cannot be considered to be exposed to quite homogeneous conditions of temperature. The influence of the temperature upon the assimilation activities of the phyto-plankton and its respiration must be the object of special investigations which we hope to be able to take up later on. In the meantime Table 6 shows that already at a depth of 10 metres there prevails equilibrity between the production and consumption of oxygen, and it appears from the tables of the alternations in temperature in the sea-water at Drøbak during the period March—April 1916 (Gran and Gaarder, 1918, p. 18) that at about March 24 the temperature was quite constant between the surface and a depth of about 20 metres, and = about 1.4° C.

A comparison of the developments at the various depths shows that none of the species bred at depths of 20 metres or more. Thus in all the flasks from 20 metres and downwards both the quantity of oxygen and the value of $P_H$ had decreased. At a depth of 10 metres most species still multiplied quite considerably, but assimilation hardly balanced respiration. The table further shows that even in the relatively faint light in March, and in spite of the fact that in addition the glass flasks must have absorbed some light, the diatoms on an average developed quite as well at a depth of 2 metres as at the surface, and even at 5 metres the daily growth is only 5 %—10 % lower than the highest. This is best seen in Table 7, where the average daily growth percent is calculated for the most important species. The others (*Biddulphia aurita*, *Melosira Borreri* and *Skeletonema costatum*) were found in the original samples of water in such scanty numbers that the sources of error of the method are of too great importance in the result.

The average daily growth of the green flagellate *Eutreptia Lanowii* is not more than 10 % and already at a depth of 5 metres is only 1 %. There is a possibility that in a closed space the flagellate in the culture does not thrive as well

as the diatoms and that therefore its breeding in the flasks may be considerably less than what would be the case in normal conditions. But on the other hand there is much that goes to show that also its normal rate of breeding is considerably less than that of the diatoms. In any case there is no doubt that we are entitled to conclude from the experiments that it requires more light than the diatoms, since already at a depth of 5 metres its breeding is only 1/10th of that at the surface. This also agrees with its occurrence in nature and with the fact that with its green colour it is best adapted to the more weakly refrangible rays of the spectrum.

This experiment showed equilibrium between assimilation and dissimilation at a depth of 10 metres; it is to be expected that corresponding experiments at other seasons will give other results. During the experiment the water was comparatively opaque on account of the density of diatom plankton. In experiments carried out by Jönsson (1903) at Drøbak with *Climacium dendroides* in July—August, the production of oxygen even at a depth of 20 metres was only just in excess of dissimilation.

The total consumption of oxygen of the plankton contained in the samples of water, including of course bacteria, was found in the experiment to be 0.03—0.07 cc. pr. l. per diem (See Table 6). The temperature must be considered to be the cause of the variations, since at the surface, between 0 and 20 metres in depth, it was about 1.5° and at a depth of 40 metres between 5° and 6°. The thickness of the surface layer at Drøbak changes from one day to another; the consumption of oxygen in the surface layer is probably not more than 0.03 cc. pr. l. per diem, whilst the higher values in the deep water correspond to the higher temperatures. It was desirable to check further the consumption of oxygen in darkness at various temperatures, just as it would be of interest to learn to what extent the consumption of oxygen is due to the actual plankton organisms, and to what extent it is due to the oxidation by bacteria of soluble organic matter in sea-water, which, according to Pütter's (1907, 1909) and Raben's (1909) investigations, may occur in comparatively considerable quantities. The following investigations were therefore made.

### Investigation, March 28—31.

From a sample of sea-water taken from the surface at Drøbak on March 28, containing a great abundance of diatom plankton and 8.86 cc. $O_2$ per litre, there was filled a litre flask which was wrapped in black cloth and suspended in the sea from 12.30 noon on March 28th to 10 a.m. on the 31st. During that time the temperature remained relatively constant = 1.8° C.

At the same time and in the same manner there was hung out a bottle of the same sample of sea-water which had been filtered beforehand through hardened filter paper that had previously been well washed out. (Schleicher & Schüll nr. 575). It was confirmed by centrifuging that this filtered sample did not con-

tain demonstrable quantities of plankton, but only a few specimens of a little *Navicula sp.* could be found. On filtration this sample lost a quantity of its oxygen so that at the beginning of the experiment it contained 8.37 cc. per litre.

| Result | $O_2$ per litre, cc. | | |
|---|---|---|---|
| | $^{28}/_{3}$ | $^{31}/_{3}$ | Consumption |
| Not filtered..... | 8.86 | 8.69 | 0.17 |
| Filtered ..... | 8.37 | 8.23 | 0.14 |

The consumption of oxygen of the non-filtered sample of water corresponds in size to the result of the foregoing experiment, 0.06 cc. per day at about 1.8° C. Its somewhat higher value is due to the circumstance that the plankton in the meantime had become considerably more abundant.

It is noteworthy that the filtered sample of water also shows so high a consumption of oxygen as 0.14 cc., i. e. about 0.05 cc. per diem.

The experiment was repeated on March 31—April 4 at various temperatures. The result will be seen in the following table. The sample of water was taken from the surface on March 31, and the flasks which were all protected against light were either suspended in the sea at a temperature of 1.6° or were kept in the cellar of the Biological Station at 3.4°, or in a cupboard in the laboratory with a temperature of about 11.5°.

| | Not filtered | | | Filtered | |
|---|---|---|---|---|---|
| Original quantity of oxygen $^{31}/_{3}$ | 9.24, 9.22 } 9.23 | | | $^{31}/_{3}$ 8.00, 8.02 } 8.01 | |
| Date | Temperature | cc. $O_2$ | Difference | cc. $O_2$ | Difference |
| $^{4}/_{4}$ | 1.6° | 9.03 | 0.20 | 7.91 | 0.10 |
| $^{4}/_{4}$ | 3.4° | 9.06 | 0.17 | 7.84, 7.82 } 7.83 | 0.18 |
| $^{4}/_{4}$ | 11.5° | 8.89 | 0.34 | 7.50 | 0.51 |

Thus the non-filtered sample has a daily consumption of 0.04—0.05 cc. $O_2$ at 1.6°—3.4°. The fact that the difference between the consumption at 1.6° and at 3.4° is contrary to what we should expect may be due to the limits of error of the method. In any case at 11° it is about double as great as at the low temperatures, or 0.09 cc. per litre (Cp. van't Hoff's R G T rule).

With this also agrees the result of the investigation of a flask, a parallel test to that which stood at 11.5° until April 4th, which was kept at 11.5° until

the afternoon of April 3rd and then placed in a bucket of ice and water at 0° until the morning of April 4th, when the analysis was made. The quantity of oxygen was 8.95 cc. per litre, consumption 0.28 cc., i. e. 0.06 cc. less in barely 24 hours than in the parallel test, which was kept the whole time at 11.5°.

The filtered samples of water as regards amount show a consumption of oxygen corresponding to that of the non-filtered samples. Viewed in relation to the non-filtered samples, however, the results are rather irregular. Yet it is quite evident that the auto-oxidation of dissolved and suspended organic matter, and the bacterial oxidation are very important factors in relation to the respiration of the phyto-plankton.

The experiment on March 22—25 (Table 7) showed so just an increase of diatoms in all the adequately illuminated flasks that it was not to be expected that the addition of nutritive salts would have increased the production. In order further to investigate this question, on March 25 there was suspended at a depth of 1 metre a number of flasks containing sea-water rich in plankton obtained from the surface, salinity 29.45 ‰. The original temperature was 1.8° and this temperature remained constant with slight variations during the whole of the experiment. The one half of the flasks was filled with unaltered sea-water from a 10 litre flask by means of a syphon; the quantity of oxygen in these flasks was 8.48 cc. per litre. The other half of the flasks was filled in the same manner from another 10 litre flask to which had been added 10 cc. of a solution of $NH_4Cl$, so that each litre received an addition of 0.05 mg. $NH_3$, and was well shaken. The amount of oxygen in this test series thereby fell to 8.20 cc. per litre. The flasks were examined in pairs, two being examined on March 28, two others remained suspended until March 31, 2 until April 3, and the last two were examined for their reaction on April 5.

The results will be seen in the following table:

| Date | | $^{25}/_{3}$ | $^{28}/_{3}$ | $^{31}/_{3}$ | $^{3}/_{4}$ | $^{5}/_{4}$ |
|---|---|---|---|---|---|---|
| A. without $NH_3$ | cc. $O_2$ | 8.48 | 9.42 | 10.23 | 10.16 | — |
| | Increase of $O_2$, cc. | — | 0.94 | 1.75 | 1.68 | — |
| | $P_H$ | 8.05 | 8.08 | 8.10 | 8.14 | 8.16 |
| B. With 0.05 mg. $NH_3$ per litre | cc. $O_2$ | 8.20 | 9.25 | 10.20 | 10.56 | — |
| | Increase of $O_2$, cc. | — | 1.05 | 2.00 | 2.36 | — |
| | $P_H$ | 8.05 | 8.10 | 8.10 | 8.14 | 8.16 |

Thus to begin with during the first 3 days, the increase in the amount of oxygen was not essentially greater in the flasks containing nitrogen fertilizer than in those containing none, but the difference increased by degrees. The amount

of oxygen in the flasks containing no ammonia even began to decrease from March 31, whilst that in those containing ammonia grew markedly. The results of the experiment will be best understood by concluding that the annual maximum of diatoms which develop at the expense of the nutritive matter present in the sea-water beforehand, already about March 25th had attained its annual maximum, so that a further increase could only take place when fresh quantities of nutritive matter were added to the sea-water.

Unfortunately we had no opportunity of continuing the experiments throughout April, and the great number of species of plankton that had developed by degrees, was less suitable for further experiments, as it is difficult to carry out the quantitative determinations of so many species with sufficient accuracy. A report will be given in the near future of a new series of experiments, carried out in March—April 1922 on the west coast of Norway; the results of these confirm the interpretation which we have given above.

There still remained the investigation on the one hand of the further relationship between the quantity of organic matter in the plankton, and on the other of the organic substances dissolved in sea-water. As is known, the degree of contamination with organic matter of a sample of water is determined from the quantity of potassium permanganate (given as cc $\frac{n}{100}$ solution used per litre of sample of water, or through the corresponding consumption of cc of oxygen) which under quite definite conditions of research is used for the oxidation of this matter. Ruppin (1904) adapted the permanganate method to the investigations of sea-water, and apart from one or two alterations in the method of procedure, we have employed Ruppin's method in our investigations. An investigation by the aid of the permanganate method, however, will always have only a limited value, since we know neither the nature of the substances which are subjected to oxidation nor how far down they are oxidised in this manner. On the other hand it is probable that comparative investigations of the oxidizability of sea-water would give information of some interest. An investigation of this kind was first carried out with samples of water collected at various depths on April 1st, (Cp. Table 5). The results will be found in Table 8, p. 37.

The quantity of organic matter which can be demonstrated by oxidation with an alkaline solution of $KMnO_4$, is thus evidently much greater in the surface water with an abundance of plankton, in this case the layers of water from 0—20 metres deep, than in the deep water with a scarcity of plankton. A minimum can be shown to exist in the transition layer at 30 metres, further downwards the quantity again increases. Even in the richest layers the values of oxidizability as to magnitude do not differ greatly from the quantity of oxygen which was produced in the course of 3 days during the cultural experiment on March 22—25 (Table 6). This should indicate that the $KMnO_4$-method in this case cannot give

any measure for the total value of organic matter in the samples of water, a result which was to be expected.

For purposes of comparison we examined two samples of water from the cultural experiments mentioned on page 13. These samples had been exposed in culture flasks at a depth of 1 metre from March 25 to April 3. In one flask, A, in which no nutritive substances had been placed, the amount of oxygen had increased in 9 days from 8.48 to 10.16 cc. per litre, i. e. by 1.68 cc. In the other flask, B, to which was added 0.05 mg. $NH_3$ per litre in the form of $NH_4Cl$, the amount of oxygen had increased during the same time from 8.20 to 10.56 cc. per litre, i. e. by 2.36 cc. per litre. Both samples were examined as to their oxidizability both unfiltered and filtered. The results were:

| Sample | | Oxidizability | |
|---|---|---|---|
| | | Consumption of cc. $\frac{n}{100}$ $KMnO_4$ per litre | Consumption of cc. $O_2$ per litre |
| A. Without $NH_3$ | Filtered..... | 12.1 | 0.68 |
| | Unfiltered ..... | 13.8 | 0.78 |
| B. With $NH_3$ | Filtered..... | 12.1 | 0.68 |
| | Unfiltered..... | 13.8 | 0.78 |

The quantities of oxygen which were consumed in the oxidation with $KMnO_4$ are thus in this case less than one half of the quantities produced by the plankton in the flasks by its photosynthesis in 9 days; this clearly shows that the permanganate method cannot give an absolute measure of the total quantities of organic matter occurring in sea-water. The difference between the sample fertilised with $NH_4Cl$ and that not fertilised is 0, between the non-filtered and the filtered samples the difference is comparatively small but constant corresponding to 0.10 cc. $O_2$.

It would appear from this that there is 5—6 times as much organic matter in a soluble or colloid-disperse condition as in the rich plankton.

Our object was, if possible, to check these results by determinations made according to another method. For that purpose 30 litres of plankton-bearing sea-water were filtered through fine chemically clean quartz sand which had been washed with distilled water, the sand being placed into a layer 2 cm. thick on bolting cloth, with a surface of about 4 $cm^2$ in an apparatus corresponding to SEDGWICK-RAFTER's filter method. It was necessary to perform the filtration under pressure. As the necessary apparatus was not available at the Drøbak Biological Station the samples of sand by the courtesy of Dr. KARL SVEEN were subjected to combustion analysis at the chemical laboratory of the Agricultural College (Norges Landbrukshøiskole) at Aas.

Before analysis the samples were dried in a drying cupboard at a temperature below 80°, and for the combustion were mixed with a little CuO in powdered form. At the first combustion (sample 1) there was used a reduced copper spiral in order thereby to remove any nitrogen oxides that might be formed. Any chlorides that might have been present would scarcely have caused any source of error, since the reduced copper spiral would certainly have bound the liberated chlorine, as it was comparatively cold during that part of the combustion when there might have been a question of formation of chlorine. In the combustion of sample 2 there were employed a copper spiral and a silver spiral. The results were:

Sample 1, 30 litres of sea-water from the surface, March 28th, gave 0.0247 g. $CO_2$, corresponding to 0.0067 g. C.

Sample 2, 30 litres of sea-water from the surface, April 1st — 0.0384 g. $CO_2$, corresponding to 0.0105 g. C. A corresponding sample of sand, examined for purpose of checking the results, gave no demonstrable quantity of $CO_2$. This thus corresponds to 0.22 and 0.35 mg. C per litre respectively, bound in the form of filterable solid substance.

For the oxidation of these quantities of carbon there should be required per litre 0.59 and 0.93 mg. $O_2$, or recalculated into volume, 0.42 and 0.65 cc. $O_2$.

The figures are of the same order of dimensions as the values according to the permanganate method, but these figures also are surprisingly small, if they are to represent the total value of so rich a quantity of plankton as that here concerned. They thus correspond to the amount of oxygen which can be produced in the course of 3 days under normal conditions in the fjord in March.

In the experiment conducted March 22nd—25th at least 0.6 cc. $O_2$ was produced at a depth of 2 metres by photo-synthesis, corresponding to 0.858 mg. $O_2$. If we assume a quotient of assimilation of 1 with the carbon mainly bound as carbohydrates, this should correspond to 0.32 mg. of carbon. If a considerable quantity of the carbon is bound as fat, the quotient will be larger, and the amount of bound carbon somewhat less, (minimum 0.2 mg.).

The gross weight of the simultaneously formed living substance may be estimated as follows:

| | | |
|---|---|---|
| 52,000 | *Lauderia glacialis* | 3 mg. |
| 47,000 | *Thalassiosira gravida* | 1.5 - |
| 24,000 | *Thalassiosira Nordenskiøldii* | 0.5 - |
| 30,000 | *Biddulphia aurita* | 1.5 - |
| 1,000 | *Eutreptia* | |
| 2,000 | *Melosira* | 0.5 - |
| 7,000 | *Skeletonema* | |

Total... 7 mg.
as maximum value.

The amount of carbon in proportion to the gross weight may from BRANDT's investigations (1898) vary quite considerably in accordance with the nature of the organisms. If we take as a basis his investigations of a sample of plankton No. VI (15 III, 1893) mainly consisting of diatoms, this should not be more than 0.45 % of the gross weight. If in order to be on the safe side we estimate this at 1 %, we obtain a value for carbon of 0.07 mg. per litre.

There should thus be produced at least 3—5 times as much organic matter as that simultaneously bound in the algæ by their increase.

We consider it to be extremely probable that this surplus is secreted from the plankton algæ in a soluble or colloid-disperse form into the sea-water, and that consequently the relatively large quantities of "soluble" organic matter which PÜTTER and RABEN found in sea-water may to a large extent be products of the metabolism of the algæ. If we take into consideration the extremely large specific surface of the plankton algæ, we must bear in mind the fact that their metabolism can be highly uneconomical. These questions, however, can only be solved by further and thorough investigations of the "soluble" organic matter in sea-water. On the one hand it is important to find other methods of determining the total amount of organic substances, independent of the permanganate method, on the other hand to find a better method (e. g. ultrafiltration after BECHHOLD) to remove all that material, which is forming the dispers phase in the sea-water, independently of the sources of error which are introduced by filtration through filter paper. There are here very interesting tasks which we hope to be able to take up again in the near future.

After these investigations were concluded PÜTTER (1925) published an account of a number of fresh investigations of the production of oxygen by plankton in light, and its consumption of oxygen in darkness at various times of the year in Kiel Bay. His values are on the whole considerably higher than the corresponding ones from our investigations. This is probably connected with the circumstance that Kiel Bay, with its marked supplies of nutritive substances from the land, has a richer plankton and bacteria life than the Oslo Fjord. When PÜTTER concludes from his calculations that the plankton can secrete up to 30 times as much of their products of assimilation as they contain in their own cells, this relative figure in comparison with our own observations appears to be rather high. As, however, we are conducting new investigations in these interesting questions, we will now not attempt to discuss the reason for the discrepancy. The most important point is that like PÜTTER we have come to the result that the plankton algæ must secrete a relatively large part of their assimilates to their surroundings. How large a part is secreted will also doubtless to a great extent depend upon the nature of the organisms and upon external conditions in the various cases.

## 2. The Plankton in the Oslo Fjord, Autumn 1917.

It was of interest to carry out parallel investigations during another period of the year for comparison with the conditions during the diatom maximum in the spring. We chose September, because at that time of the year there is usually found in the fjord a maximum of species which develop under the higher temperature.

It was known from previous qualitative investigations (Hjort and Gran 1900) and from quantitative investigations, especially in 1907—1908, and various works in the intervening years that have not been published, that the diatoms in the Oslo Fjord as a rule predominate until May, when the development concludes with an abundant plankton of *Leptocylindrus danicus* as the most prevalent species. Then in May—June there appears a relative minimum, with *Ceratium longipes*, *Peridinium depressum*, *ovatum* and *pallidum* as characteristic forms. In July—October there develops by degrees an abundance of *Ceratium* plankton with *Ceratium tripos*, *fusus* and *furca*, and a more sporadic occurrence of *Rhizosolenia alata* f. *gracillima* and *Chaetoceras curvisetum*. In certain years there may be found a more copious diatom plankton of southern species (Cleves *Didymus* plankton), in September—November, but this is only exceptionally, as in the autumn of 1893 (Hjort 1894). The quantitative occurrence of species of *Ceratium* in the summer of 1907 has been described by Gran in Murray and Hjort "Depths of the Ocean", 1912, p. 375.

We commenced the investigations by a hydrographical section of the inner part of the Oslo Fjord to Drøbak, August 28th, see Table 9. Station 1 is situated near Oslo at Nesodden, Station 2 in the middle of the inner basin of the fjord, at Steilene, Station 3 at Drøbak.

At all the stations there is a surface layer of up to 10 metres in depth, with a low and homogeneous salinity of between 20,0 ‰ and 20.6 ‰, and a temperature of 17—18° C. It is sharply differentiated from the much salter and colder deep water, with a temperature below 6° and salinity over 30 ‰. A transition layer is only found at Drøbak. Right in the fjord the boundary line is sharpest and the deep water there comes up highest towards the surface. At Drøbak the investigations had to be stopped on the 28th on account of darkness and were resumed the following morning. In the course of the night the surface layer had become somewhat thicker on account of incoming currents; at a depth of 20 metres on the 28th the water normally resembled that of the deeper layers, on the 29th there was found at the same depth a transition layer, which in all respects was more similar to the surface layers. The phytoplankton occurred abundantly in the surface layers, but very scanty in the deep water; the sparse occurrence of *Prorocentrum micans* and some other plankton species may be due to the rich surface layers from which they have sunk down.

Whilst the surface layers are saturated or oversaturated with oxygen, the

underlying layers are markedly non-saturated. The character of the plankton is on the whole homogeneous in the surface layers at all 3 stations; it is generally richest as regards most species at the innermost station, which circumstance is probably connected with the richer supply of nutritive matter from the City of Oslo. The predominant species are the three *Ceratium* species, *Ceratium tripos*, *fusus* and *furca*, further *Prorocentrum micans* and the remarkable infusoria *Mesodinium* which lives constantly in symbiosis with small, brown algæ cells. At Nesodden we also find quite large quantities of *Gonyaulax polyedra*. All these species are found in largest quantities at the innermost station, more scantily at Steilene and again somewhat more abundantly at Drøbak.

Relatively small numbers of diatoms are found; *Skeletonema costatum* and *Rhizosolenia fragilissima* occur quite abundantly at Nesodden, but are entirely lacking or occur very scantily farther out. On the contrary, *Coscinodiscus radiatus* and *Chaetoceras curvisetum* occur more abundantly at Steilene and especially at Drøbak. The same applies to the infusorium *Laboea conica*. The investigations at Drøbak were repeated a week later, on September 6th (Table 10). The situation was on the whole unchanged. The surface layer, however, had become thinner. This, in accordance with previous experience, is undoubtedly connected with the fact that the surface current in the immediately preceding days in general went outwards. This is a normal phenomenon when the surface layers differ as markedly in specific weight from the more deeply lying layers. At a depth of 10 metres we no longer find pure surface water, but a transition layer which in all respects is more like the deep layers. The composition of the plankton is the same as before, but on account of the outward current is in general somewhat more scanty. Such fluctuations occur very frequently in the Oslo Fjord and not the least so in the narrow Drøbak Sound where the currents play a very important part.

At this station there were also carried out investigations of the content of organic matter of the sea-water by the aid of the permanganate method. The samples of water were not filtered before being examined. The values are strikingly high in comparison with those found in the spring. The surface layer is decidedly the richest. Whilst on April 1st an amount of permanganate was used corresponding to 0.54—0.81 cc. $O_2$ per litre we now find corresponding values of 2.70—3.23 cc., i. e. four to five times larger. The oxidizability of the deep layers was scarcely onehalf of that of the surface layer, but was nevertheless quite considerable. In addition to the depths given in the table, samples were also examined from 50 metres and 70 metres with the following results (see p. 20):

The question is to what extent are the "soluble" organic substances derived from the plankton formed during the course of the summer and to what extent are they carried to sea from the land by fresh water.

In connection with the investigations at Drøbak on September 6th, we made investigations on September 5th in the open basin outside the Drøbak Sound and

| Depth m. | Temp. t° | Salinity ‰ | $\sigma_t$ | $O_2$ cc. per litre | % $O_2$ | $P_H$ | Oxidizability | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cons. cc. $\frac{n}{100}$ $KMnO_4$ per litre | Cons. cc. $O_2$ per litre |
| 50 | 7.82 | 31.62 | 24.67 | 5.45 | 80 | 7.87 | 21.2 | 1.19 |
| 70 | 6.07 | 32.64 | 25.70 | 5.60 | 79 | 7.87 | 19.0 | 1.06 |

thence farther in the Drammens Fjord where the surface water is almost entirely fresh on account of supplies from the River Drammen, and where on the other hand the salt water in the deep basin of the fjord is quite stagnant and contains $H_2S$, as shown previously. (Hjort and Gran, 1900).

The results of the plankton investigations are shown in tables 11—13; in the Oslo Fjord, Station 5, the plankton is in general the same as that at Drøbak, but on the whole somewhat more scanty. In the Drammens Fjord it is very scanty. We find at the surface a number of fresh water forms. At Svelvik, Station 6 we find the maximum of salt water forms in a transition layer with salinity 19.77 ‰. Here also there is a maximum saturation percentage of oxygen (95), whilst both at the surface and deeper down, the water exhibits a more marked non-saturation. At the innermost station, Station 7, in the middle of the closed basin of the Drammens Fjord, the amount of oxygen is very low for 30 metres and downwards. At a depth of 50—75 metres free oxygen is not found, but $H_2S$, with a maximum of 0.58 cc. per litre at a depth of 50 metres. At a depth of 100 metres again the water contained a little oxygen, 1.82 cc. per litre. There has thus taken place a comparatively recent inflow over the threshold of the Drammens Fjord of sea water from without, and on account of its great density the water has settled along the bottom.

Of special interest is the occurrence of organic substances, measured as consumption of cc. $O_2$ pr. l. by oxydation with permanganate, as will be seen in table 14.

The quantity of organic matter is always greatest in the surface layers and it steadily increases from Drøbak into the Drammens Fjord, as by degrees the salinity of the surface layers decreases. It reaches its maximum in the River Drammen, where the water was cloudy owing to detritus.

The values demonstrated by us at the outlet of the River Drammen agree closely with the results of the investigations which were formerly made concerning the oxidizability of the water of the River Drammen by permanganate, about 2 kilometres north of the mouth at Landfaldø Bridge. The results thus found were[1]):

[1]) Schmidt-Nielsen, S. and Printz, H., The Contamination of the River Drammen by the wood pulp, cellulose and paper mills, 1911 and 1912, Kristiania 1915, Table 19.

| Date..... | 1911 $^{24}/_{9}$ | 1912 $^{10}/_{4}$ | 1912 $^{8}/_{6}$ | 1912 $^{5}/_{7}$ | 1912 $^{3}/_{8}$ | 1912 $^{19}/_{9}$ | Average |
|---|---|---|---|---|---|---|---|
| Consumption cc. $\frac{n}{100}$ $KMnO_4$ per litre | 120 | 134 | 234 | 78 | 92 | 91 | 125 |

It is an undoubted fact that at the time of the year in question large quantities of organic matter are carried out by the river water, far larger quantities than all the plankton produced in the fjord.

During the month of September the plankton at Drøbak remained unchanged on the whole. Table 15 shows the situation on September 22nd. On the whole it is somewhat richer than at the beginning of the month. The community of species is on the whole the same as before. *Coscinodiscus radiatus* and *Ceratium furca*, however, are found in relatively larger quantities. It is a general rule that *Ceratium furca* increases in frequency during the autumn in proportion to other species.

### Cultural experiments.

In the course of the month there were carried out a number of culture experiments according to the same method as that described above. As introductory experiments there were carried out a series of investigations of the reproductory capacity of the phyto-plankton in culture flasks, which were sunk in the fjord at various depths from 2 to 40 metres. These investigations showed that even at a depth of 2—5 metres the plankton would not multiply to any great extent. We therefore laid special stress upon investigating how the plankton reacted on the addition of small quantities of $NH_3$ and phosphates, when a series of culture flasks were suspended simultaneously at a depth of 1 metre. For purposes of comparison we always suspended flasks which had been wrapped in black cloth so as to be kept in complete darkness.

Unfortunately the species predominating in September would not multiply in the culture flasks to any appreciable extent. They lived and after being in the flasks for 3 days had as a rule a normal appearance, but the increase was small or nil, so small that in any case it could not correspond to the normal conditions in the sea, where the increase of the *Ceratium* species at that time of the year is not inconsiderable. The small increase applied to peridinia and infusoria, nor did *Coscinodiscus radiatus* show any distinct growth. Nevertheless it was found that even these experiments have a certain value, since they all show a great and accordant difference between the amounts of oxygen in the illuminated and in the darkened flasks. They consequently give values for the consumption of oxygen and in any case minimum values for the production of oxygen by photosynthesis.

Experiment, 7th—10th September (72 hours). Salinity 19.71 ‰. Temperature 17.3°. $P_H = 8.16$. $O_2 = 4.58$ cc. per litre. Oxidizability corresponding to a consumption of 1.74 cc. $O_2$ per litre. Content of Plankton per litre:

*Coscinodiscus radiatus* 760, *Prorocentrum micans* 12100, *Ceratium furca* 260, *Ceratium fusus* 1000, *Ceratium tripos* 1380, *Peridinium divergens* 400, *P. Steinii* 100, *Dinophysis acuminata* 320, *D. acuta* 1280, *Gonyaulax polyedra* 280, *Mesodinium* 2320, other *Ciliata infusoria* 1500.

| | $O_2$ cc. per litre | Difference | $P_H$ | Oxidizability, consumption of oxygen in cc. $O_2$ per litre |
|---|---|---|---|---|
| With 0.05 mg. $NH_3$ pr. litre | 4.45 | — 0.13 | 8.19 | 1.76 |
| Without addition | 4.42 | — 0.16 | 8.19 | — |
| Without addition, in darkness | 4.12 | — 0.46 | 8.14 | 1.78 |

Experiment, 12th—15th September (72 hours). Salinity 19.47 ‰, temperature 16.3°, $P_H = 8.12$. Content of plankton per litre:

*Coscinodiscus radiatus* 2100, *Ceratium furca* 820, *Ceratium fusus* 5720, *Ceratium tripos* 550, *Peridinium divergens* 2010, *P. pallidum* 50, *Dinophysis acuta* 360, *Gonyaulax polyedra* 210, *Prorocentrum* not counted, *Infusoria ciliata* 400.

| | $O_2$ in cc. per litre | Difference $O_2$ | $P_H$ | Oxidizability | |
|---|---|---|---|---|---|
| | | | | Consumption cc. $\frac{n}{100}$ $KMnO_4$ per litre | Consumption cc. $O_2$ per litre |
| Series I. | | | | | |
| Before experiment | 6.16 | | 8.12 | | |
| a) In darkness | 5.70 | — 0.46 | 8.05 | 32.6 | 1.82 |
| b) Without addition | 6.08 | — 0.08 | 8.11 | 35.8 | 1.99 |
| c) With 0.05 mg. $NH_3$ per litre (as $NH_4Cl$) | 6.14 | — 0.02 | 8.12 | 36.2 | 2.02 |
| d) With 6 mg. Maltose per litre | 6.10 | — 0.06 | 8.08 | 69.2 | 3.87 |
| Series II. | | | | | |
| Before experiment | 6.21 | | 8.12 | | |
| a) In darkness | 5.78 | — 0.43 | 8.05 | 31.9 | 1.78 |
| b) Without addition | 6.20 | — 0.01 | 8.12 | 32.4 | 1.81 |
| c) With 0.05 mg. $NH_3$ per litre (as $NH_4Cl$) | 6.22 | 0.01 | 8.12 | 35.8 | 2.00 |
| d) With 6 mg. Maltose per litre | 6.08 | — 0.13 | 8.10 | 74.1 | 4.14 |

Both series are in close accordance with each other. The consumption of oxygen in darkness is large, on an average 0.445 cc. per litre. The addition of ammonia caused a scarcely noticeable increase in assimilation, on an average 0.04 cc. $O_2$ per litre in comparison with the non-fertilised flasks. The addition of 6 mg. of maltose per litre increased the oxidizability to a remarkable degree, and is found to correspond to a consumption of about 37.5 cc. $\frac{n}{100}$ $KMnO_4$ per litre.

Experiment, 18th—22nd September (94 hours). Salinity 20.43 ‰, temperature 15.1°, $P_H = 8.26$ (at the conclusion of the experiment the temperature was 14.2°). The content of plankton per litre:

*Coscinodiscus radiatus* 1260, *Ceratium furca* 8320, *Ceratium fusus* 9100, *Ceratium tripos* 5780, *Dinophysis acuta* 3920, *Peridinium divergens* 200. *Prorocentrum* and infusoria not counted.

| | $O_2$ in cc. per litre | Difference $O_2$ | $P_H$ | Oxidizability: Consumption cc. $\frac{n}{100}$ $KMnO_4$ per litre | Oxidizability: Consumption cc. $O_2$ per litre |
|---|---|---|---|---|---|
| Series I. | | | | | |
| Before experiment | 6.69 | | 8.26 | | |
| In darkness | 6.15 | — 0.54 | 8.20 | 32.8 | 1.84 |
| Without addition | 6.68 | — 0.01 | 8.26 | 33.3 | 1.87 |
| $KNO_3$ corresponding to 0.05 mg. $NH_3$ per litre | 7.09 | 0.40 | 8.31 | — | — |
| $Na_3PO_4$ corresponding to 0.03 mg. P. per litre | 6.86 | 0.17 | 8.28 | 34.3 | 1.92 |
| Series II. | | | | | |
| Before experiment | 6.75 | | 8.26 | | |
| In darkness | 6.27 | — 0.48 | 8.23 | 33.5 | 1.88 |
| Without addition | 6.70 | — 0.05 | 8.26 | 33.3 | 1.87 |
| $KNO_3$ corresponding to 0.05 mg. $NH_3$ per litre | 7.00 | 0.25 | 8.31 | 33.2 | 1.86 |
| $Na_3PO_4$ corresponding to 0.03 mg. P. per litre | 6.88 | 0.13 | 8.28 | 33.3 | 1.87 |

There is also here a close agreement between both series. The consumption of oxygen in darkness was on an average 0.51 cc. per litre. On this occasion the addition of both nitrate and phosphate respectively gave considerable positive reactions, both as regards values of oxygen and of $P_H$. The quantity of organic matter i. e. the oxidizability with potassium permanganate remained essentially unchanged by the conditions of culture.

Still better positive results were given by the last experiment, carried out on the 27th—30th September (72 hours), Table 16. The sample of water employed had during the experiment a temperature of about 13.9°, salinity 22.48 ‰, $P_H = 8.07$. The content of plankton was qualitatively the same as before, with the exception that there were demonstrable quantities of *Chaetoceras curvisetum*, *Leptocylindrus danicus* and *Rhizosolenia fragilissima*, all of which multiplied more or less in the culture flasks and gave distinct reactions for the various additions of nutritive salts.

The results concerning these diatoms are shown in Table 16. The other species, which did not multiply or which in any case showed a doubtful increase, were per litre:

*Coscinodiscus radiatus* 1109, *Distephanus speculum* 773, *Ceratium furca* 269, *Ceratium fusus* 2069, *Ceratium tripos* 383, *Dinophysis acuta* 680, *Peridinium divergens* 120, *Prorocentrum micans* 4247, *Mesodinium* 1813.

The amount of oxygen showed little or no increase in the non-fertilised flasks and in a flask to which was added $Na_3PO_4$, corresponding to 0.03 mg. P. per litre. In one flask which was kept in darkness, the consumption of oxygen was 0.47 cc., i. e. approximately as much as in the previous experiments. On the contrary, the growth was very considerable in those flasks to which had been added $NH_4Cl$ or $KNO_3$, and greatest of all in those to which had been added one of these sources of nitrogen and phosphate. (Series I, d, e). As regards oxygen, the nitrate in both series gave much greater results than the ammonium salt. As we find no corresponding difference in the increase of the diatoms, we may conceive the possibility of there being formed free oxygen by the decomposition of the nitrates. But even with complete decomposition there could not be liberated more than about 0.10 cc. $O_2$ per litre. This would not even be sufficient to cover more than about one-third of the difference.

The results might perhaps be so interpreted that the diatoms in the flasks containing nitrate fertilizer produced more organic matter in their cells than those in the flasks without this fertilizer.

The determinations of the oxidizability in this experiment were only carried out in the case of certain samples. These show no distinct difference between the unfertilised and the fertilised flasks. On the other side, the quantity of oxidisable organic matter in the flask which was kept in darkness decreased by a value corresponding to a consumption of oxygen of 0.3 cc. i. e. about two thirds of the total consumption of oxygen of this culture flask.

The growth of the diatoms in the flasks containing nitrogen fertilizers was greater than ever shown before. With nitrogen and phosphorus *Chaetoceras curvisetum* increased one hundred fold. This corresponds to a daily growth of 350—360 %, or to an average division of the cells $6^1/_2$ times every 72 hours. With phosphate alone the growth is also much greater than without addition. It corresponds

to 60 % per 24 hours or on an average 2 divisions in 72 hours. The most striking effect of the addition of phosphate was that all the cells had formed resting spores, which are otherwise not found in any of the other flasks.

In Series II it will be seen that the supply of nitrogen alone has given a smaller production of oxygen than that given by the nitrogen and phosphorus together. When the number of cells in the original sea-water sample (Sample IIa) is as small as in the present case, the determination is less accurate than in the first series, and the calculated values for growth are perhaps somewhat too high. Unfortunately we had no opportunity of repeating the experiment.

In the case of *Rhizosolenia fragilissima* the figures run somewhat parallel. The increase on the whole is somewhat less. The last two species in the table, *Leptocylindrus danicus* and *Cerataulina Bergonii* were not found in demonstrable quantities in the original sample, but multiplied to a fair stock by the addition of nitrogen.

We may venture to conclude from this experiment that the surface water in the Oslo Fjord in September does not contain sufficient quantities of soluble nutritive salts to enable neritic diatoms to develop profusely. But by the addition of nutritive salts in comparatively small quantities to those found in sea-water in other conditions three days were sufficient to bring forth at 13—14° a production which approximates the maximum value for these species.

One more culture experiment was made on October 1st—2nd, with a duration of 31 hours. The water had originally a temperature of 12.5°, salinity = 21.38 ‰, quantity of oxygen = 6.63 cc. per litre. On the morning of October 2nd there was bright sunshine, which continued until the evening when the flasks were taken up.

The quantities of oxygen were:

| | Increase |
|---|---|
| a) In darkness 6.54 cc. | ÷ 0.09 cc. |
| b) Without addition, 6.84 cc. | 0.21 cc. |
| c) With $NH_4Cl$ corresponding to 0.05 mg. $NH_3$ per litre, 7.01 cc. | 0.38 cc. |
| d) With $KNO_3$ corresponding to 0.05 mg. $NH_3$ per litre, 7.10 cc. | 0.47 cc. |

This time the growth without addition was greater than otherwise. Otherwise the results did not differ materially from the foregoing ones.

It was desirable to obtain a survey for the entire year of the variations in the quantities of organic matter in the sea-water, in connection with the variations in the hydrographic conditions otherwise. Miss Astrid Karlsen carried out such determinations in the fjord off the Biological Station, from the conclusion of our experiments in October 1917 until and including August 1918. The method employed was that described above, and the results will be seen in Table 17. All these investigations were carried out with non-filtered samples of water.

We see that throughout the year there is a distinct line of demarcation

between a surface layer of low salinity and constantly fluctuating magnitude, and more saline deep layers with more even conditions of temperature. The volume of the surface layer, as we have shown above, may change from day to day, and investigations made at intervals of 3—4 weeks therefore do not give a true idea as to how it changes with the seasons. But observations taken in January show a strikingly even distribution according to depth, not only of temperature and salinity, but also of oxygen and organic matter. It is possible that at that season of the year there took place a mixture of the layers of water by vertical circulation. It is also possible that it is a case of "packing" of one layer of water caused by the conditions of wind.

The quantity of organic matter, with the exception of that found during the observations in January, is greater in the surface layer than deeper down, but the alterations from one month to another are not great. At no other time of the year there were found such high values as at the beginning of September 1917, when the oxidation required a consumption of permanganate corresponding to 3.23 cc. $O_2$ per litre at Drøbak, and still higher values in the Drammens Fjord. Otherwise the quantities are not much more than one half of this value.

There can scarcely be any direct relationship between the quantities of oxidizable organic matter found by the permanganate method and the quantity of plankton. The investigations in September 1917 showed the highest values in the Drammens Fjord, where the plankton was very scanty but the supply of river water very large. On March 14th, 1918, when the diatom plankton must have been very abundant, as will be seen from the high percentage of oxygen and the $P_H$-value, the quantity of oxydizable organic substance was not essentially larger than at the beginning of February. In the months of December—January, when plankton is scarce, the figure certainly is somewhat below the value for the other months. We arrive at the result that the wealth of organic matter, oxidizable with permanganate, depends both upon the quantity of plankton and the supply of river water, but that the latter factor in the Oslo Fjord is decidedly the more important one. This is clearly seen in the accompanying figure (see p. 27), which show the connection between salinity and oxidizability of the samples of water from the Oslo Fjord and Drammens Fjord examined in the autumn of 1917. Decreasing salinity, i. e. increasing admixture with river water, is accompanied by a relatively evenly increasing oxidizability. We further arrive at the result that the permanganate method fails to give a complete idea of the total quantity of organic matter in sea-water. (Cp. page 15). It is necessary to find other methods for supplementing it, just as we must find better methods of obtaining special determinations of the soluble organic matter in sea-water on the one hand, and those quantities bound in solid form in plankton and detritus on the other. If our filter experiments have given tolerably true results, the bulk of the matter shown by means of the permanganate method should be found in a soluble and colloid-disperse form. But we dare

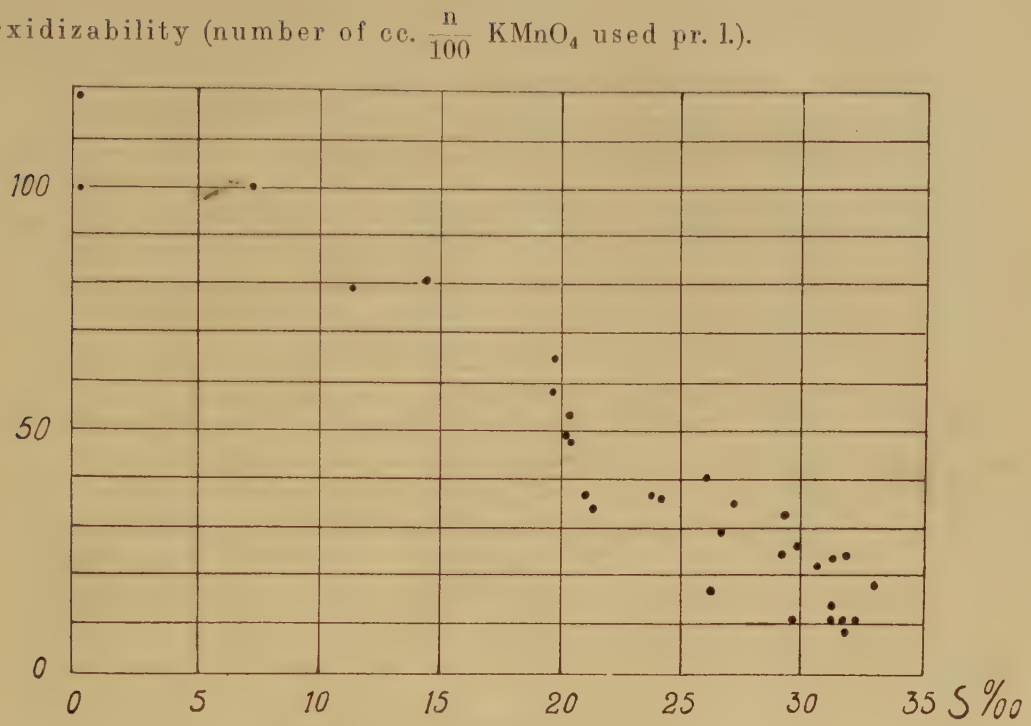


Fig. 2.

not rely upon this result before it can be checked by means of continued investigation. The question is of great interest in connection with PÜTTER's interesting theory, which after these preliminary experiments appears to find considerable support.

## Remarks concerning the various Species.

In a statistical investigation like the present one there is no opportunity of a thorough investigation of the individual species, even though in the course of the work many biological questions arise which it would be interesting to pursue further. It is also necessary for the present to renounce any possible critical account of the limitations of the species, so that the determination in the case of certain species must be regarded as preliminary. We will, therefore, content ourselves with a brief account of a number of species, the determination of which should be revised. As regards the synonymic of the other species reference is made to "Nordisches Plankton".

*Eutreptia Lanowii*, STEUER, 1903. We have provisionally referred to this species, a flagellate which regularly occurs in the Oslo Fjord in spring. It agrees

with STEUER's description both as regards its form and dimensions. Stages of division, commencing at the anterior end of the cell could also be observed somewhat often.

*Mesodinium.* This interesting infusoria plays a very important part in the plankton of the Oslo Fjord. There occur quite small specimens which have 3—4 algae cells both before and behind the cilia wreaths, and which are constricted in the middle. There also occur very large specimens with a great number of brown algae cells, and with the anterior end not spherical but spread out into the shape of a saucer or funnel. Between these there are intermediary forms, and we have not ventured to decide whether there are to be found various species, or whether there are only different stages of development. Large and small specimens may occur at one and the same time.

*Laboea.* We have retained LOHMANN's generic name, although WULFF (1916) in accordance with ANIGSTEIN (1913) combined *Laboea* and *Strombidium.* We have followed LEEGAARD (1915) as regards the limits of the various species. An interesting question which should be further investigated, is the extent to which the various species live in symbiosis with brown flagellates, as for instance *Mesodinium.* Those species which in the tables are classified under *L. conica*, *strobila* and *vestita* are as a rule very full of living brown flagellate cells, whilst *L. crassula* and *constricta* are colourless, like *Lohmanniella oviformis*, LEEGAARD (*Sphaerotrichium elegans*, Wulff).

## Resumé.

1) Quantitative plankton investigations were carried out in the Oslo Fjord at Drøbak in March—April 1916, and August—September 1917, in connection with hydrographic investigations. At both seasons of the year the abundant phytoplankton is restricted to a surface layer with a relatively low salinity; the thickness of the surface layer varies greatly from day to day, according to the wind, as previously shown (GRAN and GAARDER 1918). With an outward wind it may have a depth of about 5 metres, and with an ingoing wind up to 30—35 metres.

2) In March 1916 the main bulk of the surface plankton consisted of a large number of diatoms, which is the rule at that time of the year. The predominating species were: *Thalassiosira gravida*, *Lauderia glacialis*, and *Thalassiosira Nordenskiöldii*; the first two develop in the fjord, whilst the last appears to enter by the surface current from the Skagerak.

3) In September 1917 the predominating species were *Ceratium*, *Prorocentrum micans* and of infusoria *Mesodinium.* Of diatoms there were found in somewhat large quantities only *Coscinodiscus radiatus.* Less abundant were *Chaetoceras curvisetum* and *Rhizosolenia fragilissima.*

4) Culture experiments were made with raw plankton, the sea-water with its natural content of plankton being placed in one litre flasks with ground glass stoppers and suspended in the sea. The amount of oxygen, $P_H$ and plankton of the sea-

water was investigated before the experiment and after the plankton algae had lived in the flasks for 3 days.

5) In March the plankton diatoms exhibited a vigorous growth in all the flasks which received sufficient illumination, and the amount of oxygen increased in proportion to the development of the plankton. The value of $P_H$ also showed a distinct increase in the illuminated flasks. When a series of flasks were suspended at various depths the diatoms showed an increase down to a depth of 10 metres inclusively. At 10 metres the oxygen and $P_H$ were unchanged, at greater depths decreasing (Table 6). The maximum daily growth for diatoms was 60—80 % (Table 7). The consumption of oxygen per diem in darkness corresponds to 0.03—0.07 cc. per litre. The addition of small quantities of nitrogen and phosphorus salts at that time of the year did not increase to any appreciable extent the growth of the algae or their production of oxygen. The necessary nutritive substances thus appear to occur in March in sufficient quantities in proportion to the consumption of the diatoms.

6) In September the predominating species (*Ceratium*, *Dinophysis*, *Prorocentrum*, *Mesodinium*, *Coscinodiscus radiatus*) would not multiply in the culture flasks, whether they received nutritive substances or not. Even if none of the named species showed any increase, the addition of $KNO_3$ or $NH_4Cl$, corresponding to 0.05 mg. $NH_3$ per litre could produce an increase in the production of oxygen. In one experiment, when in addition to the above-mentioned species the culture flasks were found to contain small quantities of diatoms of *Chaetoceras curvisetum* and *Rhizosolenia fragilissima* (Table 16), those without addition of nutritive substance showed very little growth. By the addition of either $KNO_3$ or $NH_4Cl$, they showed an average growth of 200—300 % per 24 hours, corresponding to an average of 5—6 cell divisions in 72 hours. By the addition of $Na_3PO_4$, corresponding to 0.03 mg. P per litre, *Chaetoceras curvisetum* showed some growth, but formed resting spores in all cells. The addition of phosphorus in addition to the nitrogen increased the growth to some extent.

Thus, in September the surface water of the fjord did not contain a sufficient amount of nitrogen and phosphorus combinations to produce a profuse development of diatoms. By the addition of nutritive salts, three days were sufficient to form from a poor condition a profuse production of 100,000 cells per litre.

7) Investigations were made of organic matter in sea-water, determined as oxidizability of the sea-water with $KMnO_4$. The investigations were made partly with natural sea-water containing plankton, and partly with samples of water filtered through Schleicher and Schüll's hardened filters nr. 575. The filtered samples of water also gave quite high values for oxidizability, and even when the amount of plankton, as in March 1916, was very abundant, the proportion between the oxidizability of not filtered and corresponding filtered samples of

water was as 8 : 7. The consumption of oxygen by the oxidation of the plankton itself corresponds to not more than 0.10 cc. $O_2$ per litre.

8) 30 litres of sea-water containing plankton were filtered through washed, chemically clean quartz sand, which was subjected to analysis by combustion. Two different investigations of this kind gave per litre of sea-water 0.22 mg. and 0.35 mg. of carbon, corresponding to 0.42 and 0.65 cc. $O_2$ per litre, when oxidized into $CO_2$. Calculations of the production of oxygen during the culture experiments indicate that no inconsiderable portion of the assimilates of the plankton algae are diffused in a soluble form from the cells into the sea-water.

9) Organic matter determined as oxidizability with $KMnO_4$ is found as a rule in considerably larger quantities in the surface layers than in the deeper ones. Quantitative variations throughout the year (Table 17) do not always run parallel to the development of the plankton. The largest values were found in September 1917, and by far the most in the Drammens Fjord, where the plankton was very scarce, but where it could be shown that considerable quantities of oxidizable substance are carried out into the fjord from the Drammens River which is polluted by cellulose and paper mills.

The existing material gives some evidences supporting PÜTTER's interesting theory, but continued investigations are necessary.

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## Table 1. Drøbak 8th March 1916.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth, m. | 0 | 5 | 10 | 20 | 30 | 40 | 50 |
| Temperature, ° C. | 0.0 | 1.46 | 1.99 | 2.91 | 4.41 | 5.24 | 5.56 |
| Salinity ‰ | 30.08 | 31.25 | 31.58 | 32.27 | 33.31 | 33.89 | 34.08 |
| Density. $\sigma_t$ | 24.17 | 25.03 | 25.26 | 25.74 | 26.43 | 26.78 | 26.91 |
| $O_2$, cc. pr. l. | .. | 7.46 | 7.59 | 7.24 | 6.72 | 6.61 | 6.53 |
| $O_2$, % | .. | 93.0 | 96.5 | 94.5 | 92.0 | 92.5 | 92.0 |
| Number of cc. centrifuged | 100 | 160 | 100 | 100 | 100 | 100 | 100 |
| Diatoms, pr. l., sum of all spec. | 2725 | 920 | 860 | 470 | 100 | .. | 130 |
| Cerataulina Bergonii | .. | 38 | 30 | .. | .. | .. | .. |
| Chaetoceras constrictum | .. | 88 | 40 | .. | .. | .. | .. |
| — debile | .. | .. | 80 | .. | .. | .. | .. |
| — decipiens | 170 | .. | .. | .. | .. | .. | .. |
| — laciniosum | .. | 181 | 160 | .. | .. | .. | .. |
| Gyrosigma fasciola | .. | .. | .. | .. | 10 | .. | .. |
| Lauderia glacialis | 960 | 150 | 130 | 110 | 70 | .. | .. |
| Navicula sp. | .. | 6 | .. | .. | 10 | .. | .. |
| Rhizosolenia setigera | 5 | .. | .. | .. | .. | .. | .. |
| Skeletonema costatum | 50 | .. | .. | .. | .. | .. | 130 |
| Thalassiosira decipiens | 20 | 6 | 70 | .. | .. | .. | .. |
| — gravida | 780 | 438 | 350 | 360 | 10 | .. | .. |
| Thalassiothrix nitzschioides | 40 | .. | .. | .. | .. | .. | .. |
| Tropidoneis Lepidoptera | .. | 13 | .. | .. | .. | .. | .. |
| Flagellata | | | | | | | |
| Eutreptia Lanowii | 740 | 63 | 30 | .. | .. | 20 | 10 |
| Peridiniales | | | | | | | |
| Ceratium longipes | .. | 6 | .. | .. | .. | .. | .. |
| — tripos | .. | 6 | .. | .. | .. | .. | .. |
| Diplopsalis lenticula | .. | .. | 10 | .. | .. | .. | .. |
| Gymnodinium Lohmanni | 30 | 56 | .. | 10 | .. | 10 | .. |
| — sp. | .. | 25 | .. | .. | .. | .. | .. |
| Peridinium achromaticum | .. | 13 | 20 | .. | .. | .. | .. |
| — conicum | .. | 6 | .. | .. | .. | .. | .. |
| — parallelum | .. | 6 | .. | .. | .. | .. | .. |
| — pellucidum | .. | 6 | .. | .. | .. | .. | .. |
| — roseum | .. | .. | 10 | .. | .. | .. | .. |
| — sp. | .. | 19 | .. | .. | .. | .. | 10 |
| Pouchetia sp. | .. | .. | .. | .. | .. | .. | .. |
| Torodinium robustum | 80 | 19 | 20 | .. | .. | .. | .. |
| Infusoria | | | | | | | |
| Laboea conica | 10 | 19 | .. | .. | .. | .. | .. |
| — crassula | 10 | 231 | 90 | 20 | 10 | .. | .. |
| — strobila | .. | 31 | .. | .. | .. | .. | .. |
| — vestita | .. | 77 | .. | .. | .. | .. | .. |
| — sp. | .. | .. | 10 | .. | .. | .. | .. |
| Lohmaniella oviformis | 170 | 231 | .. | .. | .. | .. | .. |
| — sp. | .. | .. | 30 | 10 | .. | .. | .. |
| Mesodinium, small | .. | 75 | 260 | .. | .. | .. | .. |
| — , bigger | 20 | 513 | 60 | 20 | 30 | .. | 10 |
| Ptychocylis urnula | .. | 6 | .. | .. | .. | .. | .. |
| Tintinnopsis sp. | .. | 13 | .. | 10 | .. | .. | .. |
| Infusoria indeterminata | .. | 6 | 10 | .. | .. | .. | .. |

## Table 2. Drøbak 15th March 1916.

| | | | | | |
|---|---|---|---|---|---|
| Depth, m. | 0 | 2 | 5 | 10 | 30 |
| Temperature, ° C. | 1.0 | 5.57 | 5.69 | 6.09 | 6.25 |
| Salinity ‰ | 31.33 | 34.15 | 34.21 | 34.56 | 34.80 |
| Density, $\sigma_t$ | 25.11 | 26.95 | 26.98 | 27.21 | 27.39 |
| $O_2$, cc. pr. l. | 7.44 | 5.91 | 5.97 | 5.70 | 5.62 |
| $O_2$, % | 92.5 | 83.0 | 84.5 | 81.5 | 81.0 |
| Number of cc. centrifuged | 100 | 100 | 100 | 100 | 100 |
| Diatoms, all species, sum | 4030 | 1140 | 480 | 10 | 100 |
| Biddulphia aurita | 10 | .. | .. | .. | .. |
| Chaetoceras decipiens | 50 | 20 | .. | .. | 70[1] |
| — diadema | .. | 260 | .. | .. | .. |
| Coscinodiscus radiatus | .. | 10 | .. | .. | .. |
| Lauderia glacialis | 1150 | 110 | 130 | 10[1] | 10 |
| Licmophora sp. | 20 | 10 | .. | .. | .. |
| Navicula sp. | 20 | 20 | 20 | .. | 10 |
| Nitzschia sp. | .. | .. | .. | .. | 10 |
| Rhabdonema arcuatum | 10 | .. | .. | .. | .. |
| Skeletonema costatum | .. | 240 | .. | .. | .. |
| Thalassiosira decipiens | 250 | .. | 10 | .. | .. |
| gravida | 2200 | 470 | 300 | .. | .. |
| — Nordenskiöldii | 320 | .. | .. | .. | .. |
| Thalassiothrix nitzschioides | .. | .. | 20 | .. | .. |
| **Flagellata** | | | | | |
| Eutreptia Lanowii | 200 | 10 | .. | .. | .. |
| **Cilioflagellata** | | | | | |
| Ceratium furca | 10 | 20 | .. | .. | .. |
| Dinophysis acuta | .. | 10 | .. | .. | .. |
| Gymnodinium Lohmanni | 30 | 20 | 10 | 20 | .. |
| — sp. | .. | 10 | .. | 10 | .. |
| Peridinium pallidum | .. | .. | 10 | .. | .. |
| — sp. | .. | .. | 10 | .. | .. |
| Pouchetia sp. | .. | 10 | .. | .. | .. |
| Torodinium robustum | 60 | 10 | 10 | .. | .. |
| **Infusoria** | | | | | |
| Cyttarocylis denticulata | .. | .. | 10 | .. | .. |
| Laboea crassula | 10 | 10 | .. | .. | .. |
| — sp. | .. | .. | .. | .. | 20 |
| Lohmanniella oviformis | 40 | 90 | 70 | 30 | .. |
| Mesodinium, small | .. | 10 | 40 | .. | .. |
| — bigger | 50 | 150 | 30 | 10 | .. |
| Strombidium spinosum | .. | 10 | 70 | .. | .. |
| Tintinnus acuminatus | .. | .. | .. | .. | 10 |
| Infusoria indeterminata | 140 | 40 | .. | .. | .. |

[1] dead cells.

**Table 3. Drøbak 22th March 1916.**

| | | | | | | |
|---|---|---|---|---|---|---|
| Depth, m. | 0 | 2 | 5 | 10 | 20 | 30 |
| Temperature, ° C. | 1.0 | 1.02 | 4.68 | 5.79 | 6.14 | 6.11 |
| Salinity ‰ | 30.69 | 30.91 | 33.41 | 34.22 | 34.71 | 34.73 |
| Density, $\sigma_t$ | 24.60 | 24.79 | 26.48 | 26.98 | 27.32 | 27.35 |
| $O_2$, cc. pr. l. | 7.95 | 7.77 | 6.34 | 5.87 | 5.73 | 5.90 |
| $O_2$, % | 98.0 | 95.5 | 87.0 | 83.0 | 82.0 | 84.5 |
| $P_H$ | 7.92 | 7.95 | 7.96 | 7.98 | 7.98 | 8.02 |
| Number of cc. centrifuged | 25 | 25 | 25 | 100 | 50 | 100 |
| Diatoms, all species, sum | 26040 | 34480 | 16680 | 6060 | 60 | 240 |
| Biddulphia aurita | 120 | 680 | .. | 90 | .. | .. |
| — sinensis | .. | .. | .. | .. | 20 | .. |
| Chaetoceras decipiens | 1000 | 640 | .. | .. | .. | .. |
| — debile | 280 | 1640 | .. | .. | .. | 40 |
| — teres | 120 | .. | .. | .. | .. | .. |
| Lauderia glacialis | 9520 | 12840 | 6720 | 1960 | 40 | 30 |
| Licmophora sp. | 40 | 40 | .. | 20 | .. | .. |
| Melosira Borreri | .. | .. | .. | 380 | .. | 80 |
| Navicula sp. | .. | 40 | 80 | 20 | .. | .. |
| Nitzschia closterium | .. | .. | .. | .. | .. | 10 |
| — sp. | .. | 40 | .. | .. | .. | .. |
| Pleurosigma sp. | .. | 40 | .. | .. | .. | .. |
| Rhizosolenia semispina | .. | .. | 40 | .. | .. | .. |
| Skeletonema costatum | .. | .. | .. | 200 | .. | .. |
| Thalassiosira decipiens | .. | .. | .. | 20 | .. | .. |
| — gravida | 12720 | 15960 | 6520 | 1590 | .. | 80 |
| — Nordenskiöldii | 2240 | 2320 | 3320 | 1780 | .. | .. |
| Thalassiothrix nitzschioides | .. | 240 | .. | .. | .. | .. |
| Flagellata | | | | | | |
| Eutreptia Lanowii | 1760 | 1600 | 40 | 10 | .. | .. |
| Peridiniales | | | | | | |
| Ceratium furca | .. | .. | .. | 20 | .. | .. |
| — fusus | .. | .. | .. | 10 | .. | .. |
| Dinophysis norvegica | 20 | .. | .. | 10 | .. | .. |
| Gonyaulax sp. | 40 | .. | 40 | .. | .. | .. |
| Gymnodinium Lohmanni | 120 | .. | 40 | 50 | 20 | .. |
| — sp. | .. | 40 | .. | .. | .. | .. |
| Peridinium achromaticum | .. | 40 | .. | .. | .. | .. |
| — ovatum | .. | 40 | .. | 10 | .. | .. |
| Pouchetia sp. | 80 | 40 | 40 | 20 | .. | .. |
| Prorocentrum micans | .. | .. | .. | 10 | .. | .. |
| Torodinium robustum | 40 | 80 | .. | .. | .. | .. |
| Infusoria | | | | | | |
| Laboea crassula | 80 | 240 | .. | 70 | .. | .. |
| — strobila | 40 | 40 | .. | 20 | .. | .. |
| — vestita | 80 | 80 | 280 | .. | .. | .. |
| Lohmanniella oviformis | 80 | .. | .. | .. | 20 | 10 |
| Mesodinium | .. | 240 | 280 | 100 | 20 | .. |
| Strombidium reflexum | 80 | 160 | 40 | 10 | .. | .. |
| Infusoria indeterminata | .. | .. | .. | 10 | .. | 10 |

## Table 4. Drøbak 24th March 1916.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Depth, m | 0 | 2 | 5 | 10 | 20 | 30 | 40 | 50 |
| Temperature, ° C. | 1.7 | 1.43 | 1.38 | 1.38 | 1.62 | 3.04 | 5.38 | 6.04 |
| Salinity °/₀₀ | 30.06 | 30.10 | 30.12 | 30.23 | 30.45 | 31.93 | 34.12 | 34.71 |
| Density, $\sigma_t$ | 24.06 | 24.11 | 24.13 | 24.21 | 24.38 | 25.47 | 26.95 | 27.34 |
| $O_2$, cc. pr. l. | 8.36 | 8.31 | 8.35 | 8.26 | 7.98 | 6.92 | 6.02 | 5.88 |
| $O_2$, °/₀ | 104.0 | 103.0 | 103.5 | 102.5 | 99.5 | 90.5 | 84.5 | 84.0 |
| Number of cc. centrifuged | 10 | 20 | 10 | 10 | 25 | 25 | 50 | 50 |
| Diatoms, all species, sum | 347200 | 371450 | 476700 | 393600 | 272180 | 94820 | 7560 | 200 |
| Asterionella japonica | 200 | .. | .. | .. | .. | .. | .. | .. |
| Biddulphia aurita | 37600 | 43200 | 41000 | 58700 | 33040 | 12520 | 900 | .. |
| Cerataulina Bergonii | .. | .. | .. | .. | 80 | .. | .. | .. |
| Chaetoceras boreale | 2200 | 3400 | 2200 | 2200 | 1480 | 280 | .. | .. |
| — constrictum | 9700 | 9400 | 14000 | 14600 | 3120 | 1760 | .. | .. |
| — compressum | 7000 | 3800 | 13600 | 22500 | 6520 | 440 | .. | .. |
| — curvisetum | 2800 | 3500 | 7400 | 3600 | 1000 | 600 | 100 | .. |
| — debile | 45800 | 43400 | 58300 | 41200 | 22920 | 8920 | 300 | .. |
| — decipiens | 1000 | 1600 | 2700 | 900 | 720 | 680 | .. | .. |
| — diadema | 7000 | 11500 | 18900 | 11700 | 4760 | 720 | .. | .. |
| — breve | 200 | 200 | 200 | .. | .. | .. | .. | .. |
| — laciniosum | 9800 | 6800 | 10300 | 9300 | 3960 | 1760 | .. | .. |
| — scolopendra | 3000 | 9500 | 7500 | 5300 | 600 | 320 | .. | .. |
| — simile | 700 | .. | 200 | .. | .. | .. | .. | .. |
| — teres | 800 | 600 | 600 | 2500 | 880 | .. | .. | .. |
| Detonula cystifera | 2000 | 400 | 500 | 600 | .. | .. | .. | .. |
| Lauderia glacialis | 6000 | 6800 | 8500 | 9800 | 8160 | 6040 | 1260 | 80 |
| Leptocylindrus danicus | 800 | 500 | 1400 | 500 | 1200 | .. | 20 | .. |
| — minimus | 600 | 200 | 500 | 1500 | 720 | 840 | .. | .. |
| Navicula sp. | 1800 | 900 | 1600 | 2600 | 680 | .. | 140 | 40 |
| Nitzschia seriata | .. | 300 | 200 | 200 | 280 | .. | .. | .. |
| — delicatissima | .. | .. | 400 | .. | .. | .. | .. | .. |
| Rhizosolenia semispina | 2700 | 900 | 2000 | 1900 | 1460 | 620 | .. | .. |
| — setigera | 100 | 300 | 100 | 300 | 160 | 160 | .. | .. |
| Thalassiosira decipiens | .. | 200 | .. | 600 | .. | .. | 40 | .. |
| — gravida | 26900 | 20100 | 19500 | 22700 | 20080 | 11480 | 1300 | 80 |
| — Nordenskiøldii | 94100 | 112300 | 135500 | 165100 | 137840 | 39040 | 3420 | .. |
| — sp. | .. | 400 | 200 | .. | .. | .. | .. | .. |
| Thalassiothrix longissima | .. | 50 | 100 | .. | .. | .. | .. | .. |
| — nitzschioides | 400 | 400 | .. | 500 | 80 | 160 | .. | .. |
| Coscinodiscus radiatus | .. | .. | .. | .. | .. | 40 | .. | .. |
| Skeletonema costatum | 86000 | 90800 | 129300 | 24800 | 12440 | 8440 | 80 | .. |
| Flagellata | | | | | | | | |
| Eutreptia Lanowii | 3400 | 3700 | 4100 | 5100 | 3760 | 1040 | 40 | .. |
| Peridiniales | | | | | | | | |
| Dinophysis acuminata | .. | .. | .. | 100 | .. | .. | 40 | 20 |
| Gymnodinium Lohmanni | 200 | 50 | 400 | 500 | 320 | .. | .. | .. |
| Peridinium achromaticum | .. | .. | .. | .. | .. | 40 | .. | .. |
| — ovatum | .. | .. | .. | .. | .. | .. | 20 | .. |
| Prorocentrum micans | .. | .. | .. | .. | .. | 40 | .. | .. |
| Torodinium robustum | 100 | .. | 100 | .. | .. | .. | .. | .. |
| Infusoria | | | | | | | | |
| Laboea conica | 100 | 700 | 600 | .. | .. | .. | .. | .. |
| — crassula | .. | 200 | .. | .. | .. | .. | .. | .. |
| — strobila | .. | 50 | .. | 100 | 120 | 40 | .. | .. |
| — vestita | 3000 | 5400 | 6500 | 3500 | 720 | 80 | 20 | .. |
| Lohmaniella oviformis | 100 | 200 | 200 | 200 | 240 | 40 | .. | .. |
| Mesodinium | 900 | 1900 | 1800 | 1100 | 480 | 480 | 20 | 80 |
| Strombidium sp. | 100 | 200 | 100 | 600 | 40 | .. | .. | .. |

## Table 5. Drøbak 1 April 1916.

| | | | | | | |
|---|---|---|---|---|---|---|
| Depth, m. | 0 | 5 | 10 | 20 | 30 | 50 |
| Temperature, ° C. | 1.4 | 0.52 | 0.55 | 0.55 | 4.50 | 5.98 |
| Salinity ‰ | 24.90 | 25.05 | 25.12 | 25.42 | 33.27 | 34.85 |
| Density, $\sigma_t$ | 19.95 | 20.10 | 20.16 | 20.40 | 26.38 | 27.45 |
| $O_2$, cc. pr. l. | 8.84 | 8.84 | 8.87 | 8.80 | 6.33 | 6.03 |
| $O_2$, % | 105.5 | 103 | 103.5 | 103 | 86.5 | 86 |
| Number of cc. centrifuged | 10 | 10 | 10 | 10 | 25 | 50 |
| Diatoms, all species, sum. | 142750 | 342000 | 431750 | 258750 | 46640 | 1290 |
| Biddulphia aurita | 2900 | 18700 | 32700 | 25200 | 3440 | .. |
| — sinensis | .. | .. | .. | .. | .. | 20 |
| Chaetoceras boreale | 700 | 1100 | 1100 | 2300 | .. | .. |
| — breve | 500 | 500 | 200 | 400 | .. | .. |
| — constrictum | 700 | 3000 | 2600 | 1300 | 320 | .. |
| — compressum | 500 | 1800 | 1400 | 4300 | 680 | .. |
| — curvisetum | 1300 | 5100 | 1600 | 4300 | 1160 | .. |
| — debile | 17400 | 35400 | 29000 | 32400 | 4280 | .. |
| — decipiens | 1000 | 600 | 800 | .. | .. | .. |
| — diadema | 4000 | 4900 | 6100 | 2600 | 480 | .. |
| — laciniosum | 1100 | 2700 | 3500 | 2100 | 320 | .. |
| — scolopendra | 2000 | 4400 | 1500 | 5400 | .. | .. |
| — simile | 800 | 200 | 800 | .. | .. | .. |
| — teres | 700 | 800 | 1800 | 1400 | 80 | .. |
| Detonula cystifera | 600 | 700 | 1000 | 400 | .. | .. |
| Eucampia groenlandica | .. | .. | .. | 100 | .. | .. |
| Lauderia glacialis | .. | 100 | 200 | 900 | 7120 | 340 |
| Leptocylindrus danicus | .. | .. | .. | 400 | .. | .. |
| Navicula sp. | .. | 900 | 500 | 2000 | 40 | 20 |
| Nitzschia seriata | 800 | .. | .. | 200 | .. | .. |
| Rhizosolinia semispina | 1550 | 3050 | 3250 | 3550 | 280 | 10 |
| — setigera | 100 | 100 | 700 | 500 | 80 | .. |
| Skeletonema costatum | 99200 | 188800 | 231000 | 94100 | 4360 | 80 |
| Thalassiosira decipiens | .. | .. | .. | .. | 1600 | .. |
| — gravida | 300 | 2100 | 1800 | 5900 | 12840 | 580 |
| — Nordenskiöldii | 4800 | 64200 | 108700 | 67700 | 9520 | 200 |
| — sp. | 200 | 700 | 600 | .. | .. | .. |
| Thalassiothrix longissima | .. | .. | 100 | .. | 40 | .. |
| — nitzschioides | 1600 | 2200 | 800 | 1300 | .. | 40 |
| Flagellata | | | | | | |
| Eutreptia Lanowii | .. | 1500 | 500 | 500 | 200 | 40 |
| Peridiniales | | | | | | |
| Dinophysis norvegica | .. | .. | 100 | .. | .. | .. |
| Diplopsalis lenticula | .. | .. | 100 | .. | .. | .. |
| Glenodinium bipes | .. | 200 | 100 | .. | .. | .. |
| Gonyaulax triacantha | .. | .. | 100 | .. | .. | .. |
| Gymnodinium Lohmanni | 200 | .. | 100 | .. | .. | 40 |
| Peridinium pellucidum | .. | 200 | .. | 300 | .. | .. |
| — Steinii | .. | .. | .. | 100 | .. | .. |
| — sp. | 100 | 200 | 700 | .. | .. | .. |
| Prorocentrum micans | .. | .. | .. | .. | .. | 40 |
| Protoceratium reticulatum | .. | .. | 100 | .. | .. | .. |
| Infusoria | | | | | | |
| Laboea conica | 100 | 1200 | 200 | .. | .. | .. |
| — crassula | .. | 400 | 300 | .. | .. | .. |
| — strobila | .. | .. | 100 | 200 | .. | .. |
| — vestita | 100 | 6000 | 3600 | 500 | 40 | .. |
| Lohmanniella oviformis | .. | .. | 100 | .. | .. | .. |
| Mesodinium | .. | 600 | .. | 100 | .. | .. |
| Strombidium sp. | .. | .. | .. | 200 | .. | .. |

**Table 6. Culture experiment 22—25 March 1916.**

| | Depth, m. | Oxygen | | $p_H$ | Eutreptia Lanowii | Biddulphia aurita | Lauderia glacialis | Melosira Borreri | Skeletonema costatum | Thalassiosira gravida | Thalassiosira Nordenskiöldii |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cc. pr. l. | Difference | | | | | | | | |
| $^{21}/_{3}$ p.m. | | 7.69 | — | 7.86 | 1820 | 160 | 6700 | — | 440 | 10160 | 2540 |
| $^{22}/_{3}$ a.m. | | — | — | — | 3760 | 280 | 11040 | — | — | 15800 | 5720 |
| $^{25}/_{3}$ | 0 | 8.29 | +0.60 | 7.89 | 4960 | 5160 | 60800 | 2840 | 2640 | 63360 | 7520 |
| | 2 | 8.26 | +0.57 | 7.89 | 4880 | 30040 | 63440 | 2840 | 6880 | 62800 | 29760 |
| | 5 | 8.09 | +0.40 | 7.88 | 3840 | 23000 | 53840 | 2200 | 3560 | 58280 | 26840 |
| | 10 | 7.69 | ±0. | 7.86 | 1200 | 960 | 23080 | 960 | 3640 | 38280 | 10600 |
| | 20 | 7.60 | —0.09 | 7.82 | 360 | 1120 | 9320 | 280 | 1560 | 15120 | 4840 |
| | 30 | 7.55 | —0.14 | 7.82 | 1480 | 800 | 9760 | 80 | 1400 | 15840 | 4480 |
| | 40 | 7.47 | —0.22 | 7.82 | 1920 | 520 | 10440 | — | — | 18660 | 2280 |

**Table 7. Culture experiment 22 March—25 March 1916. Average of increase in 24 hours.**

| Depth, m. | Oxygen, cc. pr. l. | Eutreptia Lanowii % | Lauderia glacialis % | Thalassiosira gravida % | Thalassiosira Nordenskiöldii % |
|---|---|---|---|---|---|
| 0 | +0.20 | 10 | 77 | 59 | 10 |
| 2 | +0.19 | 9 | 79 | 58 | 73 |
| 5 | +0.13 | 1 | 70 | 55 | 67 |
| 10 | 0 | 0 | 28 | 34 | 23 |
| 20 | —0.03 | 0 | 0 | 0 | 0 |
| 30 | —0.05 | 0 | 0 | 0 | 0 |
| 40 | —0.07 | 0 | 0 | 0 | 0 |

**Table 8. Station 5, 1 April 1916. Depth 78 m.**

| Depth m | Temperature C° | Salinity ‰ | $\sigma_t$ | $O_2$, cc. pr. l. | $O_2$, % of Saturation | $p_H$ | Diatoms, all species, number pr. l. | Oxidizability: Number of cc. $\frac{n}{100}$ $KMnO_4$ used by oxydation pro l. seawater | Oxidizability: Number of cc. $O_2$ used by oxydation pro l. |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1.4 | 24.90 | 19.95 | 8.84 | 105.5 | 8.09 | 142750 | 14.4 | 0.81 |
| 2 | 0.55 | 25.03 | 20.09 | 9.02 | 105 | 8.09 | [1]) | 10.8 | 0.61 |
| 5 | 0.52 | .05 | .10 | 8.84 | 103 | 8.09 | 342000 | 10.1 | 0.57 |
| 10 | 0.55 | .12 | .16 | 8.87 | 103.5 | 8.08 | 431750 | 9.4 | 0.53 |
| 20 | 0.55 | .42 | .40 | 8.80 | 103 | 8.08 | 258750 | 9.6 | 0.54 |
| 30 | 4.50 | 33.27 | 26.38 | 6.33 | 86.5 | 8.00 | 46640 | 1.1 | 0.06 |
| 40 | 5.82 | 34.48 | 27.19 | 5.94 | 84 | 8.01 | [1]) | 2.7 | 0.16 |
| 50 | 5.98 | .85 | .45 | 6.03 | 86 | 8.02 | 1290 | 3.7 | 0.21 |
| 70 | 6.00 | .87 | .47 | 6.02 | 86 | 8.02 | [1]) | 3.9 | 0.22 |

[1]) not investigated.

**Table 9. St. 1. 1917. Nesodden 28 August. Depth: about 50 m.**

| Depth, m | 1 | 5 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|---|
| Temperature, °C | .. | .. | .. | 15.13 | 5.41 | .. | .. |
| Salinity ‰ | 20.43 | 20.46 | 20.49 | 30.56 | 32.04 | 32.22 | 33.15 |
| Density, $\sigma_t$ | .. | .. | .. | 22.55 | 25.20 | .. | .. |
| $O_2$, cc. pr. l. | 6.47 | 6.49 | 6.37 | 4.57 | 4.09 | 4.01 | 3.18 |
| $O_2$, % | .. | .. | .. | 76 | 57 | .. | .. |
| Number of cc. centrifuged | 100 (10) | 100 (10) | 100 | 100 | 50 | 50 | 50 |
| **Diatoms** | | | | | | | |
| Cerataulina Bergonii | 20 | 60 | 180 | .. | .. | .. | .. |
| Chætoceras curvisetum | 320 | 260 | 300 | .. | .. | .. | 100 |
| Coscinodiscus radiatus | 40 | 140 | 90 | .. | .. | .. | .. |
| Lauderia glacialis | .. | .. | .. | .. | 20 | .. | .. |
| Skeletonema costatum | 6000 | 2580 | 17380 | 60 | 1340 | .. | .. |
| Rhizosolenia fragilissima | 8240 | 7660 | 10460 | 30 | .. | .. | .. |
| **Peridiniales** | | | | | | | |
| Ceratium furca | 2620 | 2030 | 1340 | .. | .. | .. | .. |
| — fusus | 3160 | 2130 | 1870 | .. | .. | .. | .. |
| — macroceros | 10 | .. | .. | .. | .. | .. | .. |
| — tripos | 2450 | 1960 | 1050 | .. | .. | .. | .. |
| Dinophysis acuminata | 300 | 160 | 180 | 10 | 60 | 20 | .. |
| — acuta | 380 | 180 | 120 | .. | 20 | .. | .. |
| — rotundata | 180 | 20 | 100 | .. | .. | .. | .. |
| Gonyaulax polyedra | 17280 | 6680 | 3340 | 10 | .. | .. | .. |
| — spinifera | 60 | 140 | 60 | .. | .. | .. | .. |
| Peridinium achromaticum | .. | 20 | .. | .. | .. | .. | .. |
| — conicum | .. | .. | 20 | .. | .. | .. | .. |
| — depressum | .. | 20 | .. | 30 | .. | .. | .. |
| — divergens | 140 | 240 | 120 | 40 | 60 | .. | .. |
| — pallidum | 40 | 40 | 40 | .. | .. | .. | .. |
| — pellucidum | 20 | .. | .. | .. | .. | .. | .. |
| — pyriforme | .. | 20 | .. | .. | .. | .. | .. |
| — Steinii | 880 | 420 | 340 | 30 | .. | .. | .. |
| Prorocentrum micans | 35100 | 26500 | 24480 | 220 | 280 | 180 | .. |
| Torodinium robustum | .. | .. | .. | 70 | 20 | .. | .. |
| **Infusoria** | | | | | | | |
| Amphorella subulata | 180 | 80 | 300 | .. | .. | .. | .. |
| Cyttarocylis denticulata | .. | 40 | .. | .. | .. | .. | .. |
| Laboea conica | .. | 80 | 20 | .. | .. | .. | .. |
| — delicatissima | .. | .. | 40 | 10 | .. | .. | .. |
| — emergens | 120 | 240 | 340 | 10 | .. | 20 | .. |
| — strobila | 60 | 40 | 40 | .. | .. | .. | .. |
| — vestita | 60 | 380 | .. | .. | .. | .. | .. |
| Lohmanniella oviformis | 100 | 80 | 160 | 10 | 20 | 40 | .. |
| Mesodinium | 35500 | 47500 | 13320 | 320 | 580 | .. | .. |
| Tintennopsis sp. | 120 | 80 | 20 | .. | .. | .. | .. |
| Infusoria indeterminata | 460 | 440 | 140 | .. | .. | .. | .. |
| Nauplii of Copepoda | 100 | 210 | 200 | 30 | .. | .. | .. |

**Table 9** (continued). **St. 2. 1917. Steilene 28 August. Depth 53 m.**

| Depth, m. | 1 | 5 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|---|
| Temperature, ° C. | 17.59 | 17.58 | 17.71 | 8.19 | 5.51 | 5.42 | — |
| Salinity ‰ | 20.24 | 20.23 | 20.58 | 29.59 | 32.08 | 32.76 | 33.05 |
| Density, $\sigma_t$ | 14.14 | 14.14 | 14.39 | 23.03 | 25.32 | 25.87 | — |
| $O_2$, cc. pr. l. | 6.39 | 6.36 | 6.30 | 5.04 | 4.82 | 4.31 | 3.92 |
| $O_2$, % | 104 | 104 | 103 | 73 | 67 | 60 | — |
| Number of cc. centrifuged | 100 | 50 | 50 | 50 | 50 | 50 | 50 |
| **Diatoms** | | | | | | | |
| Chaetoceras curvisetum | 2920 | 160 | .. | .. | .. | .. | .. |
| Coscinodiscus radiatus | 180 | 170 | 120 | 40 | 40 | 40 | 20 |
| Rhizosolenia fragilissima | 100 | .. | .. | .. | .. | .. | .. |
| **Peridiniales** | | | | | | | |
| Ceratium bucephalum | 20 | 20 | .. | .. | .. | .. | .. |
| — furca | 70 | 60 | .. | .. | .. | .. | .. |
| — fusus | 480 | 460 | 20 | .. | .. | .. | .. |
| — macroceras | 30 | 10 | .. | .. | .. | .. | .. |
| — tripos | 800 | 730 | 200 | .. | .. | .. | .. |
| Dinophysis acuminata | 80 | 100 | .. | 20 | .. | 20 | .. |
| — acuta | 80 | 180 | .. | .. | .. | 20 | .. |
| — norvegica | 20 | .. | .. | .. | .. | .. | .. |
| — rotundata | 40 | 20 | .. | .. | .. | .. | .. |
| Gonyaulax polyedra | 60 | 100 | 20 | .. | .. | .. | 20 |
| Peridinium conicum | .. | 40 | 60 | .. | .. | .. | .. |
| — depressum | 20 | .. | .. | 20 | .. | .. | .. |
| — divergens | 210 | 200 | 40 | .. | .. | .. | .. |
| — Steinii | .. | 60 | 20 | .. | .. | 20 | .. |
| Prorocentrum micans | 4540 | 4300 | 2180 | 60 | 20 | 20 | 40 |
| Torodinium robustum | .. | .. | .. | 80 | .. | .. | .. |
| **Infusoria** | | | | | | | |
| Laboea conica | 940 | 720 | 140 | .. | .. | .. | .. |
| — delicatissima | 280 | 60 | .. | .. | .. | .. | .. |
| — emergens | 260 | 240 | 520 | .. | .. | .. | .. |
| — strobila | 80 | 80 | 20 | .. | .. | .. | .. |
| Lohmanniella oviformis | 80 | 160 | .. | .. | .. | 20 | .. |
| Infusoria indeterminata | 500 | 380 | 240 | .. | .. | .. | .. |
| Mesodinium | 32000 | 25580 | 5020 | 380 | 40 | 40 | 20 |
| Nauplii of Copepoda | 80 | 80 | 40 | 20 | .. | .. | .. |

**Table 9** (continued). **Stations 3—4. 1917. Drøbak 28—29 August.**

| | St. 4. 29 August | | | | St. 3. 28. August | | | |
|---|---|---|---|---|---|---|---|---|
| Depth, m. | 1 | 5 | 10 | 20 | 20 | 30 | 40 | 50 |
| Temperature, ° C. | 17.0 | 16.91 | 16.92 | 14.07 | 12.99 | 12.03 | — | 6.54 |
| Salinity ‰ | 20.16 | 20.35 | 20.57 | 24.38 | 28.24 | 28.80 | 30.12 | 32.16 |
| Density, $\sigma_t$ | 14.21 | 14.38 | 14.54 | 18.02 | 21.20 | 21.82 | — | 25.27 |
| $O_2$, cc. pr. l. | 6.27 | 6.22 | 6.18 | 5.78 | 5.57 | 5.60 | 5.48 | 6.01 |
| $O_2$, % | 101 | 100 | 100 | 91 | 88 | 87 | — | 85 |
| Number of cc. centrifuged | 100 | 100(10) | 50 | 50 | 50 | 50 | 50 | 50 |
| Halosphæra viridis | .. | 20 | .. | .. | .. | 40 | 20 | .. |
| **Diatoms** | | | | | | | | |
| Chaetoceras curvisetum | 3780 | 520 | 2340 | 1600 | .. | .. | 120 | .. |
| Coscinodiscus radiatus | 190 | 240 | 160 | 80 | 60 | .. | .. | .. |
| Thalassiothrix nitzschioides | .. | .. | .. | .. | .. | .. | .. | 220 |
| Cerataulina Bergonii | .. | .. | .. | .. | .. | .. | .. | 60 |
| **Peridiniales** | | | | | | | | |
| Ceratium bucephalum | 60 | .. | 10 | 10 | .. | 20 | .. | .. |
| — furca | 140 | 90 | 200 | 30 | .. | .. | .. | .. |
| — fusus | 1350 | 810 | 580 | 200 | .. | 20 | .. | .. |
| — longipes | 10 | .. | .. | .. | .. | 20 | .. | .. |
| — macroceros | 30 | 30 | 70 | 20 | 20 | .. | .. | .. |
| — tripos | 1320 | 1160 | 870 | 340 | .. | 20 | 20 | .. |
| Dinophysis acuminata | 80 | 220 | 120 | .. | .. | .. | .. | .. |
| — acuta | 200 | 280 | 220 | 100 | .. | .. | .. | .. |
| — rotundata | 20 | .. | .. | 20 | .. | .. | .. | .. |
| Gonyaulax polyedra | 140 | 180 | 220 | 80 | .. | .. | .. | .. |
| — spinifera | .. | 20 | .. | .. | .. | .. | .. | .. |
| Peridinium conicum | .. | .. | .. | 20 | .. | .. | .. | .. |
| — depressum | .. | .. | 30 | .. | .. | .. | .. | .. |
| — divergens | 640 | 740 | 590 | 100 | .. | .. | .. | .. |
| — pallidum | .. | 20 | 20 | .. | .. | .. | .. | .. |
| — Steinii | .. | .. | .. | .. | .. | .. | .. | 40 |
| Prorocentrum micans | 9240 | 6600 | 6200 | 3600 | 260 | 360 | 40 | 80 |
| Protoceratium reticulatum | 20 | .. | 20 | .. | .. | .. | .. | .. |
| Torodinium robustum | .. | .. | .. | .. | 80 | .. | .. | .. |
| **Infusoria** | | | | | | | | |
| Laboea conica | 660 | 560 | 1120 | 240 | 60 | 20 | .. | .. |
| — delicatissima | .. | .. | 100 | 20 | .. | .. | .. | .. |
| — emergens | 100 | 260 | 360 | 60 | 40 | 40 | 40 | 100 |
| — strobila | 50 | 180 | 100 | .. | .. | .. | .. | .. |
| Lohmanniella oviformis | 180 | 40 | 20 | 20 | 60 | 20 | .. | 60 |
| Mesodinium | 72500 | 77100 | 52200 | 7420 | 260 | 140 | .. | .. |
| Tintinnopsis campanula | 20 | .. | .. | .. | .. | .. | .. | .. |
| Infusoria indeterminata | 460 | 360 | 340 | 240 | 20 | 20 | .. | .. |
| Nauplii of Copepoda | 80 | 100 | 140 | 60 | 100 | 80 | .. | .. |

**Table 10. Station 8. 1917. Drøbak 6 Septembre.**

| | | | | | | |
|---|---|---|---|---|---|---|
| Depth, m. | 1 | 5 | 10 | 20 | 30 | 40 |
| Temperature, ° C. | 16.75 | 16.36 | 15.30 | 9.88 | 8.06 | 7.56 |
| Salinity ‰ | 19.64 | 20.21 | 26.59 | 29.14 | 30.63 | 31.26 |
| Density, $\sigma_t$ | 13.87 | 14.39 | 19.49 | 22.43 | 23.86 | 24.42 |
| $O_2$, cc. pr. l. | 6.22 | 5.96 | 5.27 | 4.94 | 4.87 | 5.04 |
| $O_2$, % | 100 | 95 | 86 | 74 | 71 | 73 |
| $P_H$ | 8.19 | 8.13 | 7.99 | 7.87 | 7.79 | 7.79 |
| Oxidizability: | | | | | | |
| Number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | 58.0 | 48.4 | 29.4 | 24.7 | 21.2 | 23.2 |
| Number of cc. $O_2$ used pr. l. | 3.23 | 2.70 | 1.64 | 1.38 | 1.18 | 1.29 |
| Number of cc. centrifuged | 100 | 100 | 50 | 50 | 50 | 50 |
| Halosphæra viridis | .. | 10 | 60 | .. | .. | .. |
| Distephanus speculum | 20 | .. | .. | .. | .. | .. |
| Diatoms | | | | | | |
| Chaetoceras curvisetum | 100 | 40 | 40 | 180 | .. | .. |
| Cerataulina Bergonii | .. | .. | .. | .. | 20 | .. |
| Coscinodiscus radiatus | 1040 | 920 | 20 | 40 | 40 | 20 |
| Rhizosolenia alata | .. | 60 | .. | .. | .. | .. |
| Peridiniales | | | | | | |
| Ceratium furca | 270 | 70 | .. | .. | .. | 20 |
| — fusus | 1230 | 880 | 60 | .. | .. | .. |
| — longipes | .. | .. | 20 | .. | .. | .. |
| — macroceros | .. | .. | 20 | .. | .. | .. |
| — tripos | 980 | 420 | .. | .. | .. | .. |
| Dinophysis acuminata | 1180 | 20 | .. | .. | .. | .. |
| — acuta | 1020 | 380 | 100 | .. | .. | .. |
| — rotundata | 100 | 40 | .. | .. | .. | .. |
| Gonyaulax polyedra | 380 | 80 | .. | .. | .. | .. |
| — spinifera | 30 | .. | .. | .. | .. | .. |
| Gymnodinium sp. | .. | .. | 40 | .. | .. | .. |
| Peridinium depressum | .. | .. | .. | .. | .. | 20 |
| — divergens | 1250 | 220 | .. | .. | .. | 20 |
| — pallidum | 130 | 40 | 20 | .. | .. | .. |
| — pellucidum | 60 | .. | .. | .. | .. | .. |
| — pyriforme | .. | 20 | .. | .. | .. | .. |
| — Steinii | 120 | 70 | 40 | .. | .. | .. |
| Prorocentrum micans | 5540 | 2340 | 600 | .. | .. | .. |
| Torodinium robustum | .. | .. | 80 | 40 | 40 | 20 |
| Infusoria | | | | | | |
| Amphorella subulata | 70 | .. | .. | .. | .. | .. |
| Cyttarocylis annulata | 40 | .. | .. | .. | .. | .. |
| — Claparedei | 20 | .. | .. | .. | .. | .. |
| Laboea conica | 400 | 1700 | 60 | .. | .. | .. |
| — delicatissima | .. | 80 | .. | .. | .. | .. |
| — emergens | 320 | 1220 | 40 | 40 | .. | .. |
| — strobila | 50 | 40 | 20 | .. | .. | .. |
| Lohmanniella oviformis | 300 | 300 | 40 | 20 | 120 | 100 |
| Mesodinium | 6880 | 4760 | 80 | 100 | 200 | 940 |
| Infusoria indeterminata | 1080 | 620 | 60 | .. | .. | .. |
| Nauplii of Copepoda | 70 | 60 | 20 | 80 | 20 | .. |

**Table 11. St. 5. 1917. 5 Septembre. Oslofjord, W. of Mölen. Depth ca. 200 m.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Depth, m. | 1 | 5 | 10 | 20 | 30 | 40 | 50 | 75 |
| Temperature, ° C. | 16.95 | 17.09 | 17.24 | 15.92 | 14.56 | 13.26 | 12.88 | 5.82 |
| Salinity ‰ | 14.43 | 20.20 | 23.87 | 29.84 | 31.15 | 31.87 | 32.64 | 33.08 |
| Density, $\sigma_t$ | 9.87 | 14.22 | 16.98 | 21.82 | 23.11 | 23.96 | 24.61 | 26.08 |
| $O_2$, cc. pr. l. | 6.11 | 6.10 | 5.36 | 5.54 | 5.63 | 5.72 | 5.70 | 6.24 |
| $O_2$, % | 95 | 99 | 89 | 93 | 93 | 93 | 93 | 88 |
| $P_H$ | 8.12 | 8.16 | 8.08 | 8.08 | 8.08 | 8.06 | 8.06 | 8.04 |
| Oxidizability: | | | | | | | | |
| Number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | 81.0 | 53.6 | 36.5 | 25.7 | 13.6 | 24.2 | — | 17.8 |
| Number of cc. $O_2$ used pr. l. | 4.52 | 2.99 | 2.04 | 1.44 | 0.76 | 1.35 | — | 0.99 |
| Number of cc. centrifuged | 100 | 50 | 100 | 50 | 50 | 50 | 50 | 50 |
| Halosphæra viridis | .. | .. | 30 | 40 | 20 | 20 | .. | .. |
| Diatoms | | | | | | | | |
| Cerataulina Bergonii | 20 | .. | .. | .. | .. | .. | .. | .. |
| Chætoceras curvisetum | 200 | 220 | .. | .. | .. | .. | .. | .. |
| Coscinodiscus radiatus | 140 | 320 | 20 | 20 | .. | 20 | 20 | 20 |
| Leptocylindrus danicus | 60 | 100 | .. | .. | .. | .. | .. | .. |
| Melosira Borreri | 320 | .. | .. | .. | .. | .. | .. | .. |
| Rhizosolenia fragilissima | 140 | .. | .. | .. | .. | .. | .. | .. |
| Peridiniales | | | | | | | | |
| Ceratium bucephalum | .. | 80 | 50 | .. | .. | .. | .. | .. |
| — furca | 70 | .. | .. | .. | .. | .. | .. | .. |
| — fusus | 570 | 80 | 50 | .. | .. | .. | .. | .. |
| — macroceros | 10 | .. | 10 | .. | .. | .. | .. | .. |
| — longipes | .. | .. | 10 | .. | .. | .. | .. | .. |
| — tripos | 210 | 20 | 20 | .. | .. | .. | .. | .. |
| Dinophysis acuminata | 40 | .. | 20 | .. | .. | 40 | .. | .. |
| — acuta | 410 | .. | .. | .. | .. | 20 | .. | .. |
| — norvegica | 20 | .. | .. | .. | .. | 20 | .. | .. |
| — rotundata | .. | .. | .. | .. | .. | 20 | .. | .. |
| Gonyaulax polyedra | 60 | .. | .. | .. | .. | .. | .. | .. |
| Gymnodinium sp. | 40 | 20 | 20 | .. | .. | .. | .. | .. |
| Peridinium conicum | 20 | .. | .. | .. | .. | .. | .. | .. |
| — divergens | 330 | 20 | .. | .. | .. | 20 | 20 | 20 |
| — pallidum | 20 | .. | .. | .. | .. | .. | .. | .. |
| — Steinii | 20 | 20 | 20 | .. | .. | 20 | .. | 20 |
| Prorocentrum micans | 2560 | 840 | 840 | 40 | .. | 40 | 60 | 100 |
| Infusoria | | | | | | | | |
| Laboea conica | 160 | 180 | .. | .. | .. | .. | .. | .. |
| — emergens | .. | 220 | 80 | .. | .. | 20 | 40 | .. |
| — strobila | 20 | .. | .. | .. | .. | .. | .. | .. |
| Lohmanniella oviformis | 200 | 20 | 80 | .. | .. | 20 | 20 | 40 |
| Leprotintinnus sp. | 20 | .. | .. | .. | .. | .. | .. | .. |
| Mesodinium | 120 | 500 | 240 | 20 | 60 | 140 | 40 | 140 |
| Tintinnopsis campanula | 20 | 40 | .. | .. | .. | .. | .. | .. |
| — sp. | .. | 80 | 40 | 20 | 20 | 80 | 40 | .. |
| Infusoria indeterminata | 200 | 140 | 60 | .. | .. | .. | .. | .. |
| Nauplii of Copepoda | 90 | 60 | 20 | 40 | .. | .. | 20 | .. |

**Table 12. Station 6. 1917. 5 Septembre. Svelvikfjord, by Knivsfjeld. Depth 16 m.**

| | | | | |
|---|---|---|---|---|
| Depth, m | 1 | 5 | 10 | 15 |
| Temperature, ° C | 16.05 | 17.55 | 18.68 | 16.05 |
| Salinity ‰ | 7.16 | 19.77 | 24.14 | 27.10 |
| Density, $\sigma_t$ | 4.49 | 13.80 | 16.87 | 19.70 |
| $O_2$, cc. pr. l. | 6.02 | 5.84 | 5.23 | 4.91 |
| $O_2$, % | 88.5 | 95 | 89 | 81 |
| $P_H$ | 7.68 | 8.08 | 8.06 | 8.04 |
| Oxidizability: | | | | |
| Number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | 100.0 | 65.0 | 36.2 | 35.0 |
| Number of cc. $O_2$ used pr. l. | 5.59 | 3.63 | 2.02 | 1.96 |
| Number of cc. centrifuged | 100 | 50 | 50 | 50 |
| Halosphæra viridis | .. | .. | 20 | .. |
| **Diatoms** | | | | |
| Chaetoceras curvisetum | .. | 600 | .. | .. |
| Coscinodiscus radiatus | 40 | 320 | 40 | 20 |
| Melosira distans | .. | 20 | 20 | .. |
| Nitzschia sigma | .. | .. | .. | 80 |
| Pleurosigma sp. | .. | .. | 20 | .. |
| Tabellaria flocculosa | .. | 40 | .. | .. |
| **Peridiniales** | | | | |
| Ceratium bucephalum | .. | 40 | 20 | .. |
| — fusus | 20 | 100 | .. | 20 |
| — hirundinella | .. | 20 | .. | .. |
| — longipes | 20 | .. | .. | .. |
| Dinophysis acuminata | .. | 20 | .. | .. |
| — rotundata | .. | 60 | .. | .. |
| Gymnodinium sp. | .. | 220 | .. | .. |
| Peridinium conicum | .. | 20 | .. | .. |
| — divergens | .. | 60 | .. | 20 |
| — pallidum | .. | 40 | .. | .. |
| — Steinii | .. | .. | 20 | .. |
| — sp. (brown) | 20 | .. | .. | .. |
| Prorocentrum micans | 40 | 20 | .. | .. |
| **Infusoria** | | | | |
| Laboea emergens | .. | 80 | .. | .. |
| — sp. | .. | 80 | .. | .. |
| Lohmanniella oviformis | 40 | 160 | 20 | 40 |
| Tintennopsis beroidea | .. | 140 | 20 | .. |
| — campanula | .. | 80 | .. | .. |
| — sp. | .. | 460 | 140 | .. |
| Infusoria indeterminata | .. | 20 | 20 | .. |
| Nauplii of Copepoda | .. | 60 | 60 | .. |

**Table 13. St. 7. 1917. 5 Septembre. Drammensfjord, by Hernæstangen.**

| | | | | | | |
|---|---|---|---|---|---|---|
| Depth, m. | 1 | 5 | 10 | 15 | 20 | 30 |
| Temperature, ° C. | 15.10 | 15.02 | 16.10 | 12.36 | 7.18 | 4.65 |
| Salinity °/₀₀ | 0.21 | 0.25 | 11.40 | 20.32 | 26.06 | 29.25 |
| Density, $\sigma_t$ | — 0.55 | — 0.53 | 7.72 | 15.22 | 20.40 | 23.19 |
| $O_2$, cc. pr. l. | 7.00 | 6.94 | 4.68 | 4.51 | 3.11 | 0.77 |
| $O_2$, °/₀ | 97 | 96 | 71 | 67 | 43 | 10 |
| $P_H$ | 7.58 | 7.58 | 7.49 | 7.59 | 7.40 | 7.40 |
| Oxidizability: | | | | | | |
| Number of cc. $\frac{n}{100}$ $KMnO_4$, used pr.l. . | 100.0 | 118.0 | 78.8 | 48.0 | 40.0 | 33.2 |
| Number of cc. $O_2$ used pr. l. | 5.60 | 6.60 | 4.40 | 2.68 | 2.23 | 1.85 |
| Number of cc. centrifuged | 50 | 50 | 50 | 50 | 50 | 50 |
| Diatoms | | | | | | |
| Coscinodiscus radiatus | 20 | .. | 20 | .. | .. | .. |
| Cyclotella sp. | .. | 20 | .. | .. | .. | .. |
| Navicula sp. | .. | 60 | .. | .. | .. | .. |
| Tabellaria flocculosa | .. | 200 | .. | .. | .. | .. |
| Peridiniales | | | | | | |
| Ceratium fusus | .. | .. | .. | .. | 40 | .. |
| — hirundinella | 60 | 40 | .. | .. | .. | .. |
| Dinophysis acuminata | .. | .. | 60 | .. | .. | .. |
| — acuta | .. | .. | 40 | .. | .. | .. |
| Gymnodinium sp. | .. | .. | 80 | 20 | 20 | .. |
| Peridinium depressum | .. | .. | .. | .. | 20 | .. |
| — sp. (brown) | .. | 40 | 100 | .. | .. | .. |
| Infusoria | | | | | | |
| Laboea emergens | 220 | .. | .. | .. | .. | .. |
| Lohmanniella oviformis | 810 | 280 | 120 | 20 | .. | 60 |
| Tintinnopsis sp. | 40 | .. | 240 | .. | .. | .. |
| Infusoria indeterminata | 20 | .. | 40 | .. | .. | .. |
| Nauplii of Copepoda | .. | .. | .. | 20 | .. | .. |

**Table 14. Organic matter in not filtered water samples, determined as consumption of cc. $O_2$ pr. l. seawater by oxydation with $KMnO_4$.**

| Depth in m. | St. 8 Drøbak °/₉ | St. 5 Oslofjord, V. of Mölen °/₉ | St. 6 Svelvik-fjord °/₉ | St. 7 Drammens-fjord °/₉ | Drammen river |
|---|---|---|---|---|---|
| 1 | 3.23 | 4.52 | 5.59 | 5.60 | 6.82 |
| 5 | 2.70 | 2.99 | 3.63 | 6.60 | 7.50 |
| 10 | 1.64 | 2.04 | 2.02 | 4.40 | .. |
| 15 | .. | .. | 1.96 | 2.68 | .. |
| 20 | 1.38 | 1.44 | .. | 2.23 | .. |
| 30 | 1.18 | 0.76 | .. | 1.85 | .. |
| 40 | 1.29 | 1.35 | .. | .. | .. |
| 50 | 1.19 | .. | .. | .. | .. |
| 75 | 1.06[1]) | 0.99 | .. | .. | .. |
| 100 | .. | 1.21 | .. | .. | .. |

[1]) 70 m.

**Table 15. Station 9. 1917. 22 Septembre. Drøbak.**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Depth, m. | 1 | 5 | 10 | 20 | 30 | 40 | 50 | 70 |
| Temperature, ° C. | 14.2 | 14.2 | 14.0 | 12.9 | 12.22 | 11.96 | 9.78 | 8.11 |
| Salinity ‰ | 20.97 | 21.41 | 26.21 | 29.73 | 31.22 | 31.75 | 31.825 | 32.12 |
| Density, $\sigma_t$ | 15.38 | 15.73 | 19.44 | 22.36 | 23.64 | 24.09 | 24.54 | 25.02 |
| $O_2$, cc. pr l. | 6.16 | 6.12 | 5.70 | 5.13 | 5.20 | 5.50 | 5.45 | 5.64 |
| $O_2$, % | 95 | 95 | 91 | 82 | 82 | 87 | 82 | 82 |
| $P_H$ | 8.13 | 8.13 | 8.10 | 8.01 | 7.98 | 7.98 | 7.94 | 7.92 |
| Oxidizability: | | | | | | | | |
| Number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | 36.5 | 34.1 | 17.1 | 10.5 | 10.7 | 10.2 | 8.2 | 10.8 |
| Number of cc. $O_2$ used pr. l. | 2.04 | 1.91 | 0.96 | 0.59 | 0.60 | 0.59 | 0.45 | 0.61 |
| Number of cc. centrifuged | 50 | 100 | 50 | 50 | 50 | 50 | 50 | 50 |
| Distephanus speculum | 140 | 100 | .. | .. | 20 | .. | .. | .. |
| Diatoms | | | | | | | | |
| Chaetoceras curvisetum | 1060 | 560 | 100 | .. | .. | .. | .. | .. |
| Coscinodiscus radiatus | 3920 | 2910 | 1590 | 760 | 260 | 100 | 40 | 40 |
| Guinardia flaccida | .. | .. | .. | 20 | .. | .. | .. | .. |
| Leptocylindrus danicus | 40 | 360 | 240 | .. | .. | .. | .. | .. |
| Rhizosolenia fragilissima | 800 | 340 | 790 | .. | .. | .. | .. | .. |
| Skeletonema costatum | .. | .. | 60 | .. | .. | .. | .. | .. |
| Peridiniales | | | | | | | | |
| Ceratium furca | 4340 | 1880 | 410 | .. | .. | .. | .. | .. |
| — fusus | 5620 | 3970 | 370 | 60 | 20 | .. | .. | .. |
| — longipes | .. | 10 | 10 | .. | .. | .. | .. | .. |
| — tripos | 960 | 2260 | 120 | .. | .. | .. | .. | .. |
| Dinophysis acuminata | 80 | 20 | .. | .. | .. | .. | .. | .. |
| — acuta | 1660 | 1760 | 140 | .. | 20 | .. | .. | .. |
| — rotundata | 20 | .. | .. | .. | .. | .. | .. | .. |
| Gonyaulax polyedra | 320 | 100 | 20 | .. | .. | .. | .. | .. |
| — spinifera | 40 | 20 | .. | .. | .. | .. | .. | .. |
| Gymnodinium Lohmanni | .. | 80 | 60 | 20 | 20 | 20 | .. | .. |
| Peridinium achromaticum | .. | .. | 20 | .. | .. | .. | .. | .. |
| — divergens | 280 | 100 | 140 | .. | .. | .. | .. | .. |
| — pallidum | .. | .. | .. | 20 | .. | .. | .. | .. |
| — Steinii | 80 | 180 | 40 | 20 | .. | .. | .. | .. |
| Prorocentrum micans | 16600 | 11180 | 3360 | 480 | 20 | .. | 20 | .. |
| Torodinium robustum | .. | .. | 60 | .. | .. | .. | .. | .. |
| Infusoria | | | | | | | | |
| Laboea conica | 580 | 440 | 80 | .. | .. | .. | .. | .. |
| — emergens | .. | 80 | 160 | 80 | 20 | .. | .. | .. |
| — strobila | 100 | 40 | .. | .. | .. | .. | .. | .. |
| — vestita | 1340 | 80 | 20 | .. | .. | .. | .. | .. |
| Lohmanniella oviformis | 80 | 100 | 40 | .. | .. | .. | .. | .. |
| — spiralis | .. | .. | 140 | .. | .. | .. | .. | .. |
| Amphorella subulata | .. | 60 | .. | .. | .. | .. | .. | .. |
| Infusoria indeterminata | 60 | 160 | .. | .. | .. | .. | .. | .. |
| Mesodinium | 1660 | 220 | 60 | 60 | 20 | .. | .. | .. |
| Nauplii of Copepoda | 40 | 20 | 20 | .. | .. | .. | .. | .. |

**Tabel 16. Culture experiment 27—30 Septembre 1917,**

| | $O_2$, cc. pr. l. | $O_2$, increase, in cc. pr. l. | $p_H$ | Oxidizability Number of cc. $O_2$ used pr. l. | | Nr. of cc. counted | Chaetoceras curvisetum cells pr. l. | Chaetoceras curvisetum dayly increase % | Chaetoceras curvisetum number of cell-divisions in 3 days | Rhizosolenia fragilissima cells pr. l. | Rhizosolenia fragilissima dayly increase % | Rhizosolenia fragilissima number of cell-divisions in 3 days | Leptocylindrus danicus cells pr. l. | Cerataulina Beryonii cells pr. l. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | sea-water not filtered | sea-water filtered | | | | | | | | | |
| Serie I | | | | | | | | | | | | | | |
| a) Before culture..... | 6.57 | .. | 8.07 | .. | .. | 175 | 1113 | .. | .. | 173 | .. | .. | .. | .. |
| b) no nutrition added .. | 6.63 | +0.06 | 8.09 | .. | 1.83 | 25 | 1520 | 11 | .. | 360 | 28 | .. | .. | .. |
| c) 0.03 mg P as $Na_3PO_4$ pr. l. ..... | 6.58 | +0.01 | 8.09 | .. | .. | 25 | [1]) 4560 | 60 | 2 | 320 | 23 | .. | .. | .. |
| d) 0.03 mg P (as $Na_3PO_4$) + $KNO_3$ equivalent 0.05 mg $NH_3$ ..... | 7.56 | +0.99 | 8.18 | 1.86 | 1.84 | 75 | 110775 | 363 | 6.5 | 7200 | 247 | 5.4 | 580 | 580 |
| e) 0.03 mg P (as $Na_3PO_4$) + $NH_4Cl$ equivalent 0.05 mg $NH_3$ ..... | 7.26 | +0.69 | 8.15 | 1.85 | .. | 150 | 104500 | 355 | 6.5 | 2080 | 129 | 3.6 | 40 | 160 |
| Serie II | | | | | | | | | | | | | | |
| a) Before culture..... | 6.58 | .. | 8.07 | .. | .. | 150 | 620 | .. | .. | 440 | .. | .. | .. | .. |
| b) no nutrition added .. | 6.56 | ÷0.02 | 8.09 | .. | .. | 25 | 2080 | 50 | .. | 1240 | 41 | .. | .. | .. |
| c) — , in darkness.... | 6.11 | ÷0.47 | 8.04 | 1.54 | .. | 25 | 1720 | 41 | .. | 80 | 0 | .. | .. | .. |
| d) $KNO_3$ equivalent 0.05 mg $NH_3$ ..... | 7.09 | +0.51 | 8.17 | .. | .. | 25 | 28920 | 260 | 5.5 | 2000 | 66 | 2.2 | 2880 | 200 |
| e) $NH_4Cl$ equivalent 0.05 mg $NH_3$ ..... | 6.83 | +0.25 | 8.15 | .. | .. | 25 | 36040 | 287 | 5.8 | 4200 | 112 | 3.3 | 5720 | 640 |

[1]) all cells with resting spores.

**Tabel 17. Hydrographic observations by Drøbak 1917—1918.**

| Time | Depth m. | t° | Salinity ‰ | $\sigma_t$ | $O_2$ cc. pr. l. | $O_2$ % | $p_H$ | Oxidizability number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | Oxidizability number of cc. $O_2$ used pr. l. |
|---|---|---|---|---|---|---|---|---|---|
| 1917. November 2 | | | | | | | | | |
| 9h50m | 1 | 7.99 | 24.76 | 19.26 | 7.03 | 98 | 8.10 | 25.89 | 1.46 |
| 1917. November 22 | | | | | | | | | |
| 9 35 | 1 | 5.40 | 24.88 | 19.67 | 7.39 | 97 | 8.02 | 20.35 | 1.14 |
| 9 50 | 5 | 8.80 | 29.13 | 22.31 | 6.18 | 90 | 8.04 | 13.14 | 0.74 |
| 10 13 | 10 | 12.00 | 31.40 | 23.83 | 5.70 | 90 | 8.07 | 11.52 | 0.65 |
| 10 30 | 20 | 10.68 | 33.08 | 25.46 | 5.70 | 89 | 8.06 | 6.46 | 0.36 |
| 10 53 | 30 | 9.10 | 33.35 | 25.64 | — | — | 8.02 | 9.48 | 0.53 |
| 11 17 | 40 | 8.60 | 33.49 | 26.11 | 5.73 | 86 | 8.02 | 5.06 | 0.28 |

| Time | Depth m. | t° | Salinity ‰ | $\sigma_t$ | $O_2$ cc pr. l. | $O_2$ % | $p_H$ | Oxidizability: number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | Oxidizability: number of cc. $O_2$ used pr. l. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1917. December 22 | | | | | |
| 10h50m | 1 | 4.60 | 29.74 | 23.57 | — | — | — | 14.83 | 0.83 |
| 11 10 | 5 | 7.48 | 31.92 | 24.95 | — | — | — | 8.11 | 0.45 |
| 11 30 | 10 | 7.90 | 32.45 | 25.30 | — | — | — | 7.12 | 0.40 |
| 11 45 | 20 | 9.32 | 33.10 | 25.60 | — | — | — | 5.04 | 0.28 |
| 12 00 | 30 | 9.60 | 33.30 | 25.70 | — | — | — | — | — |
| | | | | 1918. January 23 | | | | | |
| 13 15 | 1 | 2.40 | 32.21 | 25.73 | 7.64 | 98.5 | — | 14.71 | 0.82 |
| 13 30 | 5 | 2.03 | 32.23 | 25.78 | 7.64 | 97.5 | — | 13.53 | 0.76 |
| 14 0 | 10 | 2.10 | 32.29 | 25.82 | 7.64 | 98.0 | — | 13.14 | 0.74 |
| 14 15 | 20 | 2.10 | 32.30 | 25.83 | 7.72 | 99.0 | — | 12.75 | 0.71 |
| 14 25 | 30 | 2.10 | 32.30 | 25.83 | 7.66 | 98.0 | — | 13.73 | 0.77 |
| 14 40 | 40 | 2.20 | 32.38 | 25.88 | 7.56 | 97.0 | — | 12.26 | 0.69 |
| | | | | 1918. February 4 | | | | | |
| 14 40 | 1 | 1.10 | 27.95 | 22.42 | 8.14 | 98.5 | 8.10 | 25.51 | 1.40 |
| 14 55 | 5 | 1.41 | 28.33 | 22.69 | 7.95 | 97.0 | 8.02 | 17.40 | 0.97 |
| 15 05 | 10 | 2.12 | 29.74 | 23.78 | 7.35 | 93.0 | 7.98 | 14.63 | 0.82 |
| 15 20 | 20 | 6.43 | 34.05 | 26.77 | 6.08 | 87.0 | 7.97 | 11.19 | 0.63 |
| 15 50 | 30 | 6.62 | 34.42 | 27.03 | 6.10 | 88.0 | 7.97 | 7.52 | 0.42 |
| 16 10 | 40 | 6.67 | 34.42 | 27.03 | 6.03 | 87.0 | 7.97 | 11.47 | 0.64 |
| | | | | 1918. February 28 | | | | | |
| 14 30 | 1 | ÷0.19 | 26.26 | 21.07 | 9.17 | 105 | 8.10 | 34.05 | 1.91 |
| 14 55 | 5 | +0.04 | 26.64 | 21.40 | 9.14 | 109 | 8.05 | 23.14 | 1.30 |
| 15 05 | 10 | 0.06 | 26.87 | 21.59 | 8.96 | 104.5 | 8.02 | 21.37 | 1.20 |
| 15 17 | 20 | 4.60 | 32.59 | 26.54 | 6.51 | 89 | 7.98 | 10.26 | 0.57 |
| 15 30 | 30 | 6.00 | 33.80 | 27.69 | 6.22 | 88.5 | 7.98 | 8.19 | 0.46 |
| 15 45 | 40 | 6.41 | 34.32 | 28.08 | 6.20 | 89 | 7.98 | 7.09 | 0.40 |
| | | | | 1918. March 14 | | | | | |
| 15 0 | 1 | 0.86 | 22.50 | 18.06 | 9.82 | 113.5 | 8.12 | 27.58 | 1.54 |
| 15 15 | 5 | 0.80 | 22.95 | 18.42 | 9.94 | 115.0 | 8.15 | 23.30 | 1.30 |
| 15 30 | 10 | 0.72 | 23.33 | 18.73 | 9.63 | 111.5 | 8.15 | 22.75 | 1.27 |
| 15 45 | 20 | 2.83 | 29.18 | 23.28 | 7.68 | 98.0 | 7.98 | 16.82 | 1.09 |
| 16 0 | 30 | 5.03 | 32.86 | 26.00 | 6.63 | 91.5 | 7.98 | 9.37 | 0.52 |
| 16 15 | 40 | 5.42 | 33.31 | 26.32 | 6.46 | 90.5 | 7.98 | 9.65 | 0.54 |
| | | | | 1918. April 2 | | | | | |
| 14 45 | 1 | 1.46 | 23.01 | 18.44 | 9.07 | 107 | 8.11 | 28.66 | 1.60 |
| 15 0 | 5 | 1.48 | 23.40 | 18.76 | 9.16 | 108 | 8.11 | 23.35 | 1.31 |
| 15 12 | 10 | 1.42 | 25.10 | 20.15 | 9.18 | 113 | 8.10 | 20.00 | 1.12 |
| 15 25 | 20 | 5.00 | 33.17 | 26.24 | 6.64 | 93 | 7.96 | 8.97 | 0.50 |
| 15 45 | 30 | 5.45 | 33.60 | 26.53 | 6.22 | 86 | 7.96 | 8.06 | 0.45 |
| 16 0 | 40 | 6.30 | 34.29 | 26.97 | 6.14 | 88 | 7.96 | 8.06 | 0.45 |

| Time | Depth m. | t° | Salinity ‰ | $\sigma_t$ | $O_2$, cc. pr. l. | $O_2$ % | $p_H$ | Oxidizability: number of cc. $\frac{n}{100}$ $KMnO_4$ used pr. l. | Oxidizability: number of cc. $O_2$ used pr. l. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1918. May 13 | | | | | |
| 9h52m | 1 | 9.92 | 20.95 | 16.18 | 7.45 | 105 | 8.02 | 28.44 | 1.59 |
| 10 11 | 5 | 9.82 | — | — | 7.43 | — | — | 28.71 | 1.61 |
| 10 19 | 10 | 9.50 | 22.65 | 17.44 | 7.56 | 108 | 7.99 | 25.38 | 1.42 |
| 10 33 | 20 | 6.64 | 29.70 | 22.92 | 6.23 | 85 | 7.95 | 13.97 | 0.78 |
| 10 57 | 30 | 5.12 | 34.43 | 27.24 | 6.31 | 88 | 7.94 | 6.27 | 0.35 |
| 11 10 | 40 | 5.01 | 34.51 | 27.31 | 6.42 | 90 | 7.94 | 4.20 | 0.24 |
| | | | | 1918. June 13 | | | | | |
| 17 43 | 1 | 14.65 | 24.72 | 18.27 | — | — | 7.96 | 31.44 | 1.76 |
| 17 55 | 5 | 13.83 | 25.70 | 19.09 | — | — | 7.87 | 24.29 | 1.36 |
| 18 08 | 10 | 6.15 | 33.37 | 26.27 | — | — | 7.87 | 7.32 | 0.41 |
| 18 20 | 20 | 5.36 | 33.96 | 26.84 | — | — | 7.83 | 3.75 | 0.21 |
| 18 38 | 30 | 5.36 | 34.07 | 26.93 | — | — | 7.82 | 10.00 | 0.56 |
| 18 48 | 40 | 5.28 | 34.13 | 26.97 | — | — | 7.82 | 7.86 | 0.44 |
| | | | | 1918. July 24 | | | | | |
| 9 16 | 1 | 18.07 | 22.92 | 16.11 | 6.49 | 109 | 8.01 | 32.94 | 1.84 |
| 9 30 | 5 | 16.77 | 24.36 | 17.40 | 6.58 | 106 | 8.00 | 28.88 | 1.62 |
| 9 48 | 10 | 13.20 | 28.46 | 21.36 | 6.12 | 97 | 7.93 | 22.18 | 1.24 |
| 10 02 | 20 | 11.36 | 30.43 | 23.26 | 6.00 | 93 | 7.93 | 15.68 | 0.88 |
| 10 23 | 30 | 8.88 | 31.44 | 24.37 | 5.32 | 79 | 7.93 | 21.11 | 1.16 |
| 10 48 | 40 | 7.77 | 32.32 | 25.20 | 5.29 | 77 | 7.93 | 19.81 | 1.11 |
| 10 58 | 50 | 7.32 | 32.65 | 25.57 | 5.44 | 77 | 7.92 | 16.29 | 0.91 |
| 11 12 | 75 | 5.61 | — | — | 6.68 | — | — | 13.41 | 0.75 |
| | | | | 1918. August 19 | | | | | |
| 9 43 | 1 | 18.25 | 21.18 | 14.73 | 6.13 | 101 | 8.10 | 24.84 | 1.39 |
| 9 55 | 5 | 16.91 | 24.65 | 17.66 | 5.86 | 97 | 8.03 | 18.96 | 1.06 |
| 10 06 | 10 | 12.76 | 28.39 | 21.35 | 5.60 | 88 | 7.98 | 14.90 | 0.83 |
| 10 18 | 20 | 9.35 | 31.29 | 24.20 | 5.26 | 79 | 7.95 | 13.08 | 0.73 |
| 11 27 | 30 | 9.13 | 31.92 | 24.74 | 5.56 | 83 | 7.94 | 11.26 | 0.63 |
| 10 45 | 40 | 8.46 | 32.32 | 25.12 | 5.54 | 82 | 7.93 | 3.25 | 0.18 |
| 10 57 | 50 | 8.00 | 32.86 | 25.61 | 5.81 | 85 | 7.93 | 2.42 | 0.15 |
| 11 15 | 75 | 6.07 | 33.95 | 26.75 | 6.40 | 91 | 7.91 | 4.16 | 0.23 |